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ON THE SUBTERRANEAN MASS-ANOMALIES IN INDIA

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In India, the gravity anomalies are now available for over 350 stations and the shape of the geoid is also well determined. Taking Hayford's isostatic compensation as standard, a distribution of mass-anomalies has been determined, which would account for the gravity anomalies. When reducing gravity to sea-level, account has been taken of the separation between geoid and its reference spheroid.

We shall start by idealizing the actual Earth in such a way that all masses protruding above the geoid are removed.

The actual geoid is an equipotential of matter inside and outside it. Let all topography external to the geoid be brought inside it, and so distributed that it neutralizes its Hayford compensation. All the attracting masses are now comprised within the geoid. We will designate by compensated geoid that equipotential surface of the new mass system, which has the same potential  $V=C_0$  as the geoid.

Let  $R$  be the best fitting spheroid of this compensated geoid, so chosen that the mean potential over it is  $U=C_0$ . On reference to Fig. 1, we see that compensated geoid is equipotential of matter within uniform

spheroid R + matter A between compensated geoid and R + matter B between compensated and natural geoids + anomalies from uniformity.

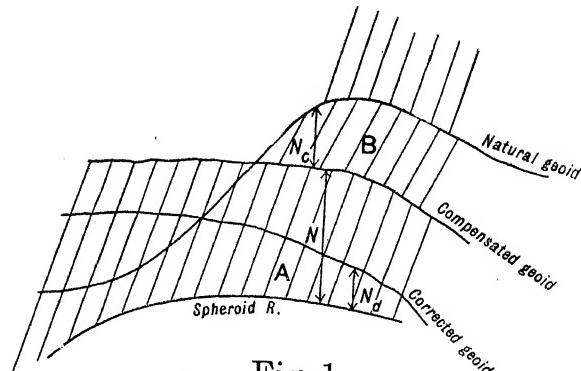


Fig. 1

These anomalies may either be deep-seated or close to the surface. In any case let their effect be equivalent to a skin distribution  $\sigma_1$  on the spheroid. Hence, compensated geoid is equipotential of uniform spheroid + skin density  $\sigma_1$  + matter  $\rho$  ( $N + N_c$ ), (see Fig. 2) where  $\rho$  denotes the density of the Earth's crust,  $N_c$  the height of the natural geoid above the compensated geoid, and  $N$  the height of the compensated geoid above the spheroid R. Our new mass system then is a uniform spheroid R + a skin density  $\sigma_1 + \rho (N + N_c) = \sigma$  on it.

We will designate by corrected geoid that equipotential surface of this new mass system which has same potential as the compensated geoid. Let the height of the corrected geoid above the spheroid be  $N_d$ . The undulations  $N_d$  of the corrected geoid with respect to the spheroid R are due to the skin density  $\sigma$ .

The corrected geoid may be below the spheroid at places where the skin density is negative. But  $N_d$  is small, and at such places, the skin density may be presumed to be shifted from the spheroid to the geoid, so that the formula for external potential is still applicable to points on the corrected geoid.

The spheroid R may be replaced by a sphere of mean radius R. Potential  $\delta v$  due to a sphere of radius R with a coating  $\sigma = \Sigma \rho Y_n$  at an external point is

$$\begin{aligned} \delta v &= 4\pi f\rho R \sum \frac{1}{2n+1} \left(\frac{R}{r}\right)^{n+1} Y_n \\ &= 4\pi f\rho R \sum \frac{Y_n}{2n+1} \text{ at } r=R \quad . . . . . \end{aligned} \quad (1)$$

Since the spheroid and the corrected geoid have the same potential,  $N_d = \frac{\delta v}{G}$

$$= \frac{3}{2.07} \sum \frac{Y_n}{2n+1} \quad . . . . . \quad (2)$$

Attraction at  $r=R$  due to this coating is

$$\begin{aligned} \Delta g_T &= -\frac{\delta}{\delta r} (\delta v) = 4\pi f\rho \sum \frac{n+1}{2n+1} Y_n \\ &= 2\pi f\rho \sum \left( Y_n + \frac{Y_n}{2n+1} \right) \\ &= 2\pi f\rho \left[ \frac{\sigma_1 + (N+N_c)\rho}{\rho} + \frac{2.07}{3} N_d \right]. \quad . . . (3) \end{aligned}$$

If  $g_d$  is gravity on the corrected geoid, and  $\gamma_0$  on the spheroid excluding the attraction of  $\sigma$ , then

$$\begin{aligned} (g_d - \gamma_0) &= \Delta g_T - \frac{2G}{R} N_d \\ &= 2\pi f\rho \left[ \frac{\sigma_1 + (N+N_c)\rho}{\rho} + \frac{2.07}{3} N_d - \frac{8.28}{3} N_d \right] \\ &= 2\pi f\sigma_1 + 2\pi f\rho (N+N_c - 2.07N_d) \quad . . . (4) \end{aligned}$$

Let  $\sigma_1$  be equivalent to a thickness of  $H$  feet of rock of normal density, i.e.,  $\sigma_1 = \rho H$ .  $H$  represents the mass-anomaly measured in feet of rock of normal density.

$$\text{Then } H = \frac{1}{2\pi f\rho} (g_d - \gamma_0) - (N+N_c - 2.07N_d) \quad . . . . . \quad (5)$$

Now  $f = 6.68 \times 10^{-8} \text{ cm}^3/gm \text{ sec}^2$  and  $\rho = 2.67$ ,

$$\therefore H \text{ feet} = 29.3 \times 10^8 (g_d - \gamma_0) - (N+N_c - 2.07N_d). \quad . . . . . \quad (6)$$

Our object now is to find  $g_c - g_d$  and  $N - N_d$ , and then we will get the required relation between  $g_c$ ,  $N$  and  $H$ . Let  $P$  be a point on the compensated geoid, and  $P_d$  a point on the corrected geoid, vertically below or above it. From Fig. 2, we see that

$$g_c = \left( \gamma_0 - \frac{2\gamma_0 N}{R} \right) + \text{attraction of } \sigma_1 + \text{attraction of matter } \rho (N+N_c) \text{ at } P.$$

$$g_d = \left( \gamma_0 - \frac{2\gamma_0 N_d}{R} \right) + \text{attraction of coating } \{\sigma_1 + \rho(N + N_c)\} \text{ at } P_d.$$

$g_e - g_d = \{\text{attraction of matter } \rho(N + N_c) \text{ at } P - \text{attraction of coating}$

$$\rho(N + N_c) \text{ at } P_d\} + \frac{2\gamma_0}{R}(N_d - N) \quad . . . . . \quad (7)$$

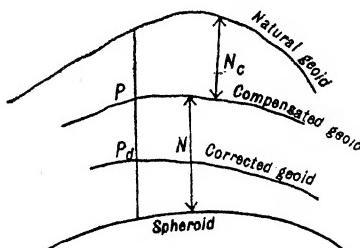


Fig. 2.

The first term could be readily computed, if  $\rho(N + N_c)$  were known over the whole globe. According to Hirvonen,<sup>1</sup> if one uses the best fitting spheroid,  $\rho(N + N_c)$  varies from  $-270 \text{ ft.}$  to  $+270 \text{ ft.}$  over the whole Earth. Its average value irrespective of sign is  $\pm 160 \text{ ft.}$ , and with regard to sign is 0. We know that for a uniform spherical shell, the attraction of near parts is equal to attraction of remote parts. In our case  $\rho(N + N_c)$  fluctuates with a mean amplitude of  $\pm 160 \text{ ft.}$  and its average value is zero. We can reasonably assume that the effect of the remote portions on the first term of equation (7) is negligible. We are thus concerned with the effects of near portions alone.  $P$  and  $P_d$  being within a few feet of each other, the first term of (7) is approximately twice the attraction of matter  $N_c$ . In peninsular India,  $N_c$  has a maximum value of  $10 \text{ ft.}$ ; under the Himalayas it may attain a value as big as  $100 \text{ ft.}$ . Hence, neglecting mountainous areas, the first term of (7) is less than  $0'001 \text{ cm/sec}^2$ . The second term  $\frac{2\gamma_0}{R}(N_d - N)$  corresponds to  $'001 \text{ cm/sec}^2$  for  $N_d - N = 10 \text{ ft.}$  The average difference between the compensated and corrected geoids is much less than this, hence for all practical purposes,  $g_e$  may be put equal to  $g_d$ .

In (6), the effect of the second term is small as compared to the first, and we can put  $N_d = N$ . This will hardly introduce an error of a few feet. Our final expression for the anomaly becomes

$$H \text{ feet} = 29'3 \times 10^3(g_e - \gamma_0) - (N_c - N). \quad . . . . . \quad (8)$$

Now  $\gamma_0 = G_E (1 + A \sin^2 \phi + B \sin^2 2\phi)$ , where the constant  $B$  is determined theoretically, and  $A$  depends upon the ellipticity of the reference spheroid.  $G_E$  is an arbitrary constant, whose exact value cannot be ascertained. It is generally obtained by a least square solution, using the fact, that the observed values of  $g$  should agree as best as possible with those obtained theoretically. Applying the above criterion, Silva proposed at the International Union of geodesy and geophysics at Stockholm in 1930, that the gravity formula for the International spheroid should be

$$\gamma_0 = 978.049 (1 + 52884 \times 10^{-7} \sin^2 \phi - 59 \times 10^{-7} \sin^2 2\phi) . \quad (9)$$

This formula was given universal acceptance. The gravity anomalies in India with reference to (9) are exhibited on Chart XIV of the Survey of India Geodetic Report for the year 1934.  $N$  and  $N_e$  can be read off from Charts XXII and XXIII of the same publication. The values of  $(g - \gamma_e)$ ,  $N$  and  $N_e$  were read from the above charts for every degree square. The resulting mass-anomalies on substituting these values in (8) are shown in Chart I.

These anomalies however need a further correction. The International spheroid for the purpose of gravity anomalies is so oriented that its centre coincides with the centre of gravity of the compensated geoid. The Charts XXII and XXIII of Geodetic Report 1934 have been deduced from deflection data in India only and the orientation of the spheroid is defined by the separation of the geoid and spheroid and the plumb-line deflections at the geodetic datum Kaliānpur. The gravity anomalies and the geoidal elevations in Geodetic Report charts are therefore not in the same terms.

Hirvonen in Table 11 of his paper<sup>1</sup> gives the elevations of the geoid above the International spheroid oriented in such a way that the centres of gravity of the two surfaces are coincident. According to him, the geoid in the whole of India is depressed below the spheroid. Comparing his table with Chart XXII, it appears that the latter needs a correction of about  $-210ft.$  to bring it into International terms. Hence, the mass-anomalies exhibited in Chart I need a correction of  $-210ft.$

This chart may be compared with Chart XIV of Geodetic Report, Vol. V of Survey of India, where the mass-anomalies were deduced without making any use of the gravity anomalies. The differences are very striking. The large positive anomalies round Jubbulpore and Sambalpur have now disappeared. Ceylon is now an area of negative anomaly instead of an area of excess. The changes are due to our imperfect knowledge of the geoid in 1928. As an example, near Ceylon, the geoid was taken as being above the spheroid while the 1933-34 work shows it to be

an area of depression, in conformity with the low values of gravity obtained there.

We see that the Gangetic plain is an area of underload, the deficiency being equivalent to a skin density of  $-500$  to  $-2000 \text{ ft.}$  of rock condensed on the spheroid. These are very much smaller than the corresponding anomalies in Geodetic Report V, where they attained a maximum value of  $-6700 \text{ ft.}$  in this area. The difference is partly due to the fact that these latter were supposed to be distributed between sea-level and a depth of 70 miles, while now we have condensed them on the spheroid.

The anomalies have also been measured, taking the Survey of India spheroid II as standard. This spheroid is so chosen that it fits the compensated geoid in India best. The gravity formula adopted for this spheroid is

$$\gamma_0 = 978'021 (1 + 0'005,234 \sin^2 \phi - 6 \times 10^{-6} \sin^2 2\phi).$$

The value 978'021 for  $G_E^2$  was determined from a least square solution, so that the observed gravity values in India fit best the above formula values. Chart II shows the mass-anomalies with respect to this standard. The two Charts I and II are very similar. It should be noted that no correction is necessary to the mass-anomalies as shown in Chart II, as the Survey of India spheroid II is fitted only to the Indian portion of the compensated geoid, and its C.G. is not coincident with the C.G. of the Earth. The value of  $G_E$  is also deduced from the Indian gravity stations only.

#### SUMMARY

From the Isostatic gravity anomalies in India, a distribution of mass anomalies expressed as a coating of normal crustal density on the reference surface has been determined. Account has been taken of masses between geoid and its reference surface. Two reference surfaces have been considered; the International spheroid, and the Survey of India, spheroid II. The anomalies are exhibited in Charts I and II.

#### References

1. 'The continental undulations of the geoid' by R. A. Hirvonen. Veröffentlichungen des Finnischen Geodätischen Institutes, No. 19.
2. Survey of India, Geodetic Report, Vol. V, p. 55.

Chart I

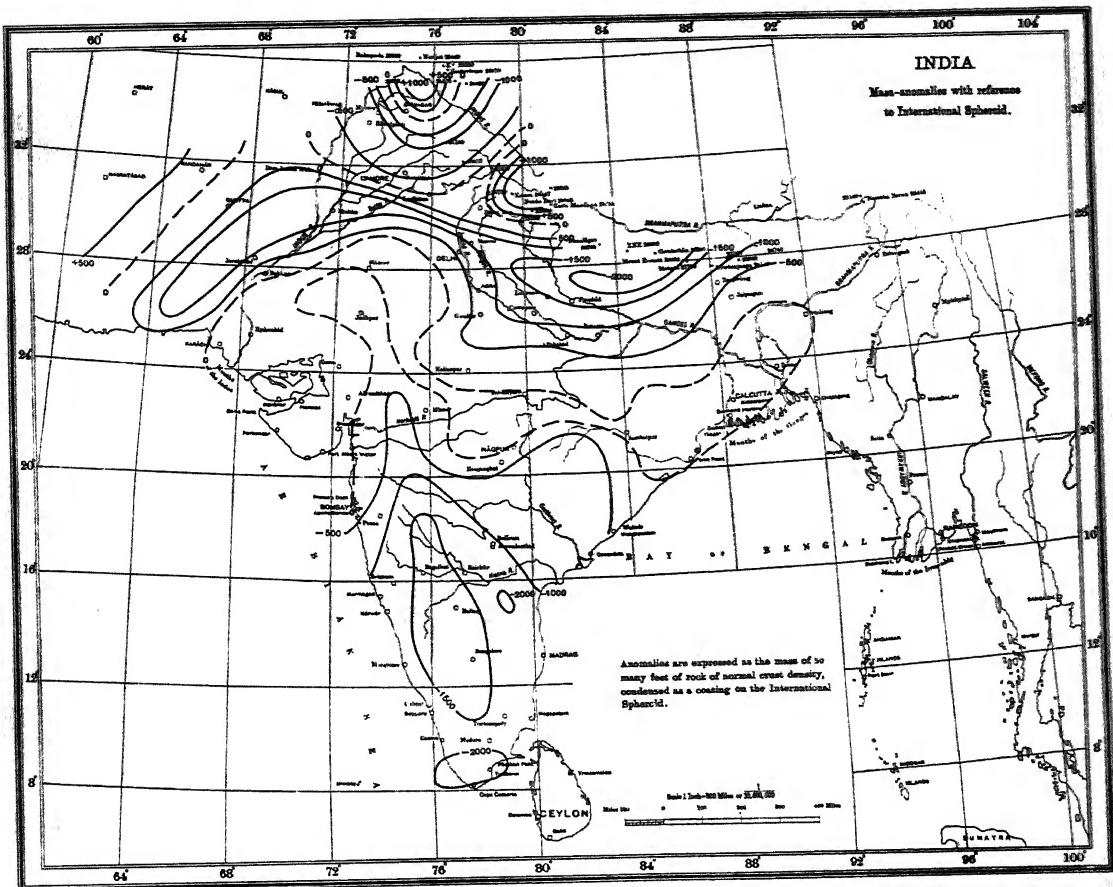
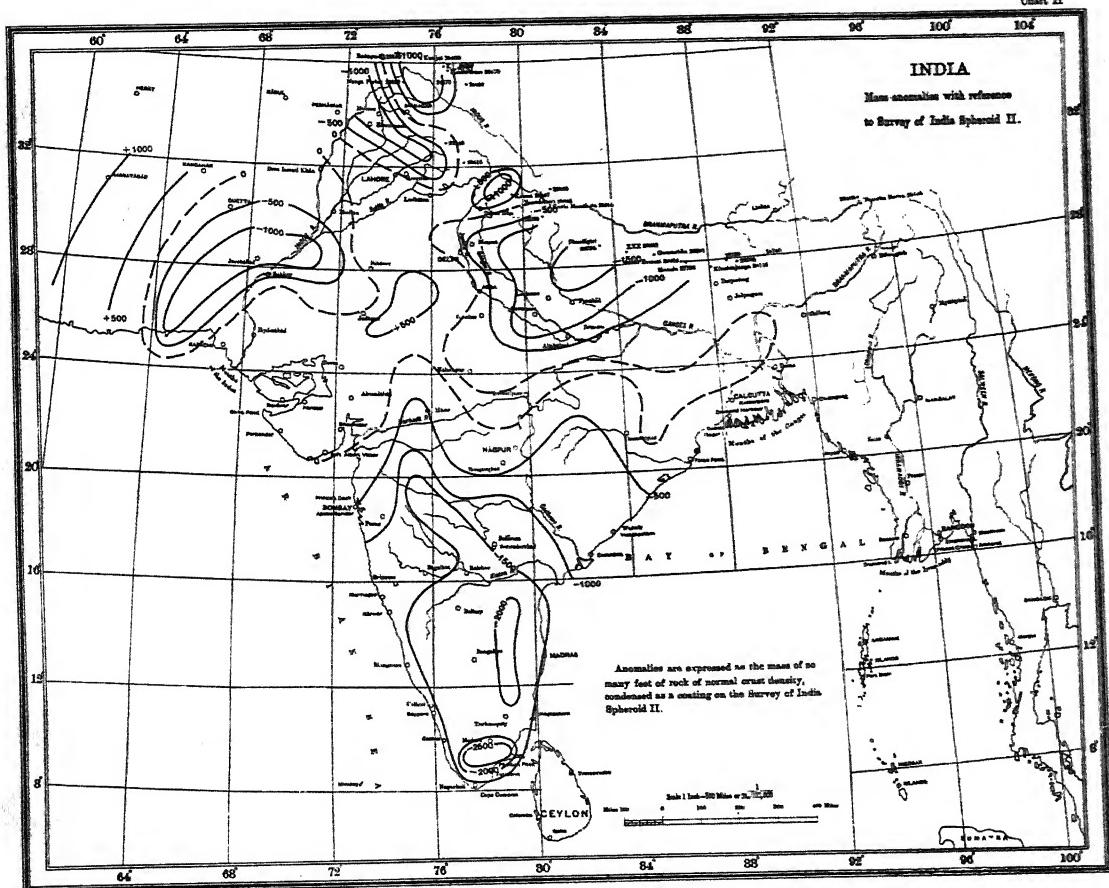


Chart II



# THE CLOSURE PROPERTY OF THREE CURVES

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1. Wertheimer writes in the Bulletin of the American Mathematical Society for February, 1934 : "Let  $C_1, C_2, C_3$ , be three plane curves such that  $C_2$  lies between  $C_1$  and  $C_3$ ; take any point  $P$  on  $C_2 \dots$  Project  $P$  vertically on  $C_3$  into  $P_3, \dots P_3$  horizontally on  $C_1$  into  $P_1, \dots P_1$  vertically on  $C_2$  into  $P_2, \dots P_2$  horizontally on  $C_3$  into  $P'_3, \dots P'_3$  vertically on  $C_1$  into  $P'_1$ , finally project  $P'_1$  on  $C_2$  into  $P'$ . If the points  $P$  and  $P'$  coincide for all points on  $C_2$ , the three curves are said to have the closure property." He then proceeds to consider a singly infinite system of curves and enunciates a theorem concerning any three of these that may have the closure property. A close study of this theorem has suggested the thoughts that have been put down below.

2. Consider the system of curves (assumed to be continuous in an assigned interval),

$$\alpha_i f(x) + \beta_i \phi(y) + \gamma_i = 0 \quad . \quad . \quad . \quad . \quad . \quad (A)$$

the axes of coordinates being the horizontal and the vertical at a fixed point, and  $\alpha, \beta, \gamma$  being independent while  $i$  runs through all values.

Let  $C_1$  be given by  $\alpha_1 f(x) + \beta_1 \phi(y) + \gamma_1 = 0$ ; similarly  $C_2$  and  $C_3$ . Further let  $P$  be  $(x, y)$ ;  $P_3, (x, y_3)$ ;  $P_1, (x_1, y_3)$ ;  $P_2, (x_1, y_2)$ ;  $P'_3, (x'_3, y_3)$ ;  $P'_1, (x'_3, y')$ ; and  $P', (x', y')$ . Then the series of projections gives

$$\alpha_2 f(x) + \beta_2 \phi(y) + \gamma_2 = 0 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\alpha_3 f(x) + \beta_3 \phi(y_3) + \gamma_3 = 0 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\alpha_1 f(x_1) + \beta_1 \phi(y_3) + \gamma_1 = 0 \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\alpha_2 f(x_1) + \beta_2 \phi(y_2) + \gamma_2 = 0 \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$\alpha_3 f(x'_3) + \beta_3 \phi(y_2) + \gamma_3 = 0 \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$\alpha_1 f(x'_3) + \beta_1 \phi(y') + \gamma_1 = 0 \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Multiply (1) by  $\beta_1 \alpha_3$ , (2) by  $-\beta_1 \alpha_2$ , (3) by  $\beta_3 \alpha_2$ , (4) by  $-\beta_3 \alpha_1$ , (5) by  $\beta_2 \alpha_1$ , (6) by  $-\beta_2 \alpha_3$  and add; then

$$\beta_1 \beta_2 \alpha_3 [\phi(y^1) - \phi(y)] = \begin{vmatrix} \alpha_1 & \beta_1 & \gamma_1 \\ \alpha_2 & \beta_2 & \gamma_2 \\ \alpha_3 & \beta_3 & \gamma_3 \end{vmatrix} \quad . \quad . \quad . \quad . \quad . \quad (B)$$

3. Let  $\begin{vmatrix} \alpha_1 & \beta_1 & \gamma_1 \\ \alpha_2 & \beta_2 & \gamma_2 \\ \alpha_3 & \beta_3 & \gamma_3 \end{vmatrix}$  vanish when  $\beta_1, \beta_2, \beta_3$  are different from zero.

In this case  $\phi(y') = \phi(y)$  for all values of  $y$ ; if now  $y$  is in one-to-one correspondence with  $\phi(y)$  it follows that  $y' = y$ . For instance if  $\phi(y) = e^y$ , the resulting equation  $e^{y'} = e^y$  leads to  $y' = y$ . Moreover if  $\phi(y)$  is of the form  $Ay^n + B$ ,  $n$  being an odd integer positive or negative,  $y' = y$  is the only real result derived from  $\phi(y') = \phi(y)$ . Again when  $\phi(y')$  is equal to  $\phi(y)$ ,  $f(x') = f(x)$ ; this immediately gives  $x = x'$  when  $f(x) \equiv Cx^m + D$  where  $m$  is an odd integer positive or negative and in general when a given value of  $f(x)$  implies only one value for  $x$ .

Now  $\begin{vmatrix} \alpha_1 & \beta_1 & \gamma_1 \\ \alpha_2 & \beta_2 & \gamma_2 \\ \alpha_3 & \beta_3 & \gamma_3 \end{vmatrix} = 0$  is simply the condition that  $C_1, C_2, C_3$

may have at least one common point; hence if three curves of system (A) have a common point, they have the closure property.

N.B.—It is to be understood that  $f(x)$  and  $\phi(y)$  define a single real value for  $x$  and  $y$  respectively.

By taking  $\phi(y) = y, f(x) = x$ , it may be seen that any three concurrent lines have the closure property. This can be verified independently.

4. Let one  $P'$  coincide with  $P$ ; then the determinant

$\begin{vmatrix} \alpha_1 & \beta_1 & \gamma_1 \\ \alpha_2 & \beta_2 & \gamma_2 \\ \alpha_3 & \beta_3 & \gamma_3 \end{vmatrix} = 0$ . Now the argument of section (3) will

show that in general, if one point on  $C_2$  returns to its old position after the sequence of projections, all points on  $C_2$  will do the same, i.e., the three curves will have the closure property. Thus in a sense the closure property with respect to three curves may be said to be poristic.

By assigning various forms to  $\phi(y)$  and  $f(x)$ , various interesting results may be deduced concerning circles, parabolas, ellipses, etc.

## MEASUREMENT OF IONIZATION OF THE KENNELLY- HEAVISIDE LAYER AT ALLAHABAD

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### Introduction

In March 1902, Kennelly,<sup>1</sup> and a few months later Heaviside<sup>2</sup> independently put forward the view that an ionized region existing at a height of about 80 Km. plays an important part in the propagation of radio waves. The direct proof of the presence of such an ionized region was lacking till 1925, when Appleton and Barnett<sup>3</sup> definitely got evidence of the existence of an ionized layer at a height of 80 Km. Later in 1927, Appleton<sup>4</sup> proved the existence of another layer at an height of about 250 Km.

In February, 1925, Appleton,<sup>5</sup> and a few months later Nichols and Schellung,<sup>6</sup> independently pointed out that refraction and absorption in the Ionosphere should be considerably modified by the Earth's magnetic field. It has since been shown that the radio wave would be split up into two components by magnetic double refraction, and one of these would be more highly absorbed than the other.

### Theoretical

The theory of propagation of electromagnetic waves in an ionized medium in the presence of magnetic field was given by Lorentz<sup>7</sup> in 1909. He dealt with two special cases—propagation of electromagnetic waves along the magnetic field and propagation perpendicular to the magnetic field—which cannot always be applied to the general problem of propagation of radio waves.

In 1927, Breit<sup>8</sup> showed quantitatively the effect of the earth's magnetic field on a ray propagated in any direction with respect to the earth's magnetic field. A few months later Appleton<sup>9,10,11</sup> independently solved the same problem and gave an equation for the refractive index.

On generalising the Lorentz's theory it can be easily shown that when absorption is negligible, for vertical propagation

$$\mu^2 = 1 + \frac{2}{2\alpha - \frac{\gamma_T^2}{1+\alpha} \pm \sqrt{\frac{\gamma_T^4}{(1+\alpha)^2} + 4\gamma_L^2}} \quad . . . . . \quad (1)$$

Where,

$$\alpha = -\frac{n^2 m}{Ne^2} - a; \gamma_T = \frac{nh_z}{Ne} \text{ and } \gamma_L = \frac{nh_x}{eNe};$$

$h_z$  and  $h_x$  are the  $Z$  and  $X$ -components of the earth's magnetic field, the radio wave is supposed to be propagated along the  $X$ -axis.

Reflection occurs when  $\mu=0$ . Now from (1) it can be shown that  $\mu=0$ , when,

$$\left. \begin{array}{l} 1+\alpha = -(\gamma_T^2 + \gamma_L^2)^{1/2} \\ 1+\alpha = 0 \\ 1+\alpha = +(\gamma_T^2 + \gamma_L^2)^{1/2} \end{array} \right\} \quad (a) \quad (b) \quad (c) \quad . . . . . \quad (2)$$

Thus theory points out that three concentrations will give rise to three echoes. But usually only two echoes are visible corresponding to conditions (a) and (b) of formula (2). Corresponding to (2,a) we get an extraordinary ray (the shorter delay component) and corresponding to (2,b) we get an ordinary ray (the longer delay component). Reflections corresponding to (2,c) involving a higher concentration of electrons is generally not observed. However, under specially favourable circumstances triplets evidently belonging to the same system have been observed in this laboratory<sup>12</sup> and elsewhere<sup>13</sup> thus completely establishing the validity of the magneto-ionic theory.

There is a lot of controversy about the value of  $a$  in the formula for  $\alpha$ . Appleton,<sup>14</sup> Hartree<sup>15</sup> and others are of the opinion that  $a=\frac{1}{3}$  as used by Lorentz, but Tonks and Norton<sup>16</sup> do not agree with this view and have advanced reasons for using  $a=0$ . If  $f_c$  is the lowest frequency which penetrates the ionised layer, we can easily see from (2,b) that

$$N = \frac{m\pi}{(1-a)e^2} f_c^2 = 1.86 \times 10^{-8} f_c^2 \text{ if } a=\frac{1}{3}$$

$$\text{and } N = 1.24 \times 10^{-8} f_c^2 \text{ if } a=0.$$

The above value of  $N$  then gives the maximum value of the number of electrons in the region which has been penetrated by  $f_c$ .

### EXPERIMENTAL

The present paper deals with the ionization of the E-layer at Allahabad (Lat.  $25^{\circ} 26' N.$  Long.  $81^{\circ} 35' E.$ ). The principle of the method is very simple. A radio pulse of about  $10^{-4}$  sec. duration is radiated vertically upwards and the reflected echo is observed on a cathode ray oscillograph. The necessary apparatus for the success of the experiment has been described elsewhere<sup>17, 18</sup>. Both the transmitter and the receiver are situated side by side in the same room. The only change in these experiments and those already reported is that while in the previous experiments the frequency was kept constant, during these experiments the frequency was changed by steps of about 50 kilo-cycle/sec. An inverted L aerial was used for the radiation of the pulses. A combination of an earth screen and an ordinary copper plate earth was used for earthing purposes. The frequency of the transmitter was increased till echoes failed to be reflected from the E-layer and echoes from the F-layer appeared. It usually took about a minute to change the frequency of the transmitter and the retuning of the receiver. Thus within a few minutes the penetration frequency could be easily determined from which the ionization could be calculated.

### RESULTS

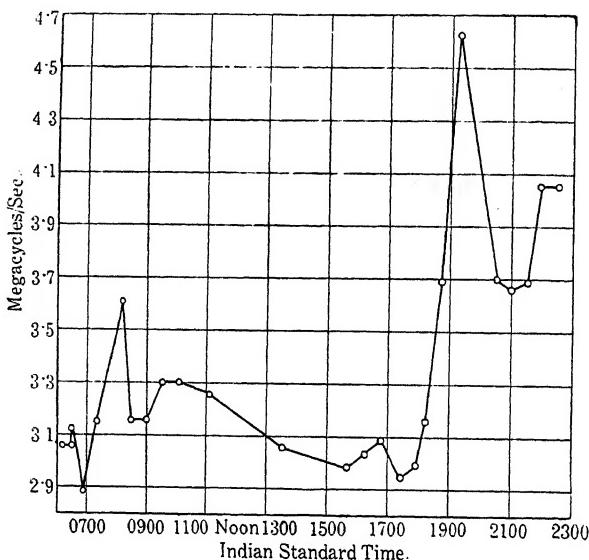
In the early morning as well as the evening hours very near the critical frequency retarded echoes from the E-layer and simultaneous echoes from the E-layer and the F-layer were seen.

Though F-layer echoes were visible during midday in the month of December, 1934, it was impossible to get F-layer echoes in April during midday. The usual phenomenon observed during the midday period on increasing the frequency was that at a certain frequency no reflection was visible from the E region, but no echo from the F region could be seen. The highest frequency at which the E-echo was last seen was taken as the critical frequency of the E-layer.

A typical graph representing the conditions on various days after the 15th April is given below. It shows a higher value of the critical frequency in the morning and rather a low value during the midday period. There is very great increase in  $f_E$ , the E region critical frequency at about 1922 I. S. T.

A little before sunrise the ionization increased rather abruptly and retarded E echoes were observed side by side with the F echoes, which may be single or double. Later on the intensity of the echoes became

very feeble due to absorption in the lower regions and often near about noon nothing was visible on the oscilloscope screen. The electrical disturbances also increased as the day advanced and the echoes were sometimes masked by them for an hour or more. The intensity of the echoes, however, increased during the afternoon and evening hours.



With little exception the ionization after sunset again increased. On some occasions the ionization of the E region increased very considerably and strong reflections were visible even for frequencies as high as 4.6 Mc/sec.

#### DISCUSSION OF THE RESULTS

The graph representing the ionization on the 18th April shows rather an anomalous behaviour, which seems to be apparent rather than real. The most probable explanation of the low value of the critical frequency of the E region in the middle of the day is that there is a lot of absorption in the lower atmosphere, and the strength of the transmitted signals have to be increased before a real value for  $f_E$  can be found. This explanation seems to be all the more probable in view of the fact that even on increasing the frequency beyond the apparent critical frequency no reflections were visible from the F region.

Thus it definitely appears that on increasing the power of the present transmitter, which is only 100 watt at present; this anomaly will

disappear and our results will be more in accord with the results obtained by others. In view of the above explanation, not much reliance has been placed on the midday values of the critical frequencies.

The work is being continued and it is hoped that within a short period a high power transmitter will be installed, and it will be possible to find out not only the ionization of the E region but also of the F region throughout the twenty-four hours.

Our hearty thanks are due to Prof. M. N. Saha, F.R.S., for his continued interest in the work and also for the facilities given to us for the success of this investigation.

[Note added in proof correction September 11, 1935—The curve given in this paper shows a marked similarity to the curve obtained by Kirby, Berkner and Stewart<sup>19</sup> and by Appleton and Naismith<sup>20</sup> for summer noon ionization of the F<sub>2</sub> region. Kirby and coworkers think that the determination of the F<sub>2</sub> critical frequency during summer is spurious due to marked absorption; but Appleton and Naismith think that the F<sub>2</sub> critical frequency measurements are real. They explain that the noon minimum is due to a real low value of the number of electrons in the F<sub>2</sub> region and estimate that the lowest molecular temperature in that region is 1200°K. In a recent discussion on the Ionosphere held under the auspices of the National Institute of Sciences, India, one of us<sup>21</sup> suggested that in view of our experiments—which definitely show that the double maxima for the E region critical frequency is due to the absorption of energy by the lower ionized layer—there is every likelihood of removing the summer noon minimum anomaly in the case of the F<sub>2</sub> region critical frequency measurements, if more power than that hitherto used, is employed for such measurements. Thus if the absorption hypothesis is correct only one maximum at noon will be found, but if Appleton's view is correct then again the same type of curve will be obtained.]

#### SUMMARY

The ionization of the E region has been found in the month of April. Due to increased absorption in the lower atmosphere a low value of the critical frequency has been obtained during the midday period and is not to be relied upon, but the values for the morning and evening which show high values are very reliable and show that on an average the morning critical frequency was in the neighbourhood of 3·1 Mc./sec. at 8 A.M. The maximum value of the critical frequency 4·6 Mc./sec. was observed on the 18th April during the so-called 'evening concentration' at 1922 I.S.T. (5½ hours ahead of G.M.T.)

In the note added in proof correction it is pointed out that the similarity between the observed critical frequency and that of the  $F_2$  critical frequency curve obtained by Appleton and others shows that the two maximum in the latter curve may be due to absorption. It is also suggested that more power should be used for finding out  $F_2$  critical frequency in order to decide between the high temperature theory of Appleton and the absorption hypothesis of Kirby and others.

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ON THE APPLICATION OF HEAVISIDE'S OPERATIONAL  
METHODS TO THE SOLUTION OF THE  
PIANOFORTE PROBLEM

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In the present paper Heaviside's operational methods<sup>1</sup> have been used to obtain a complete solution of the pianoforte problem. Heaviside has shown that solutions of differential equations connected with physical problems can be easily and quickly obtained when the initial or boundary conditions are known. Heaviside's unit function and the expansion theorem are sufficient to complete the solution

If  $y = \frac{Y_\sigma}{Z_\sigma}$ , where  $Y_\sigma$  and  $Z_\sigma$

are polynomials in  $\sigma = \frac{d}{dt}$ , and  $y_\sigma$  is of the same or lower degree in  $\sigma$  than  $Z_\sigma$ , then

$$y = \frac{Y_\sigma=0}{Z_\sigma=0} + \sum \frac{Y_\sigma}{\sigma Z_\sigma} e^{\sigma t} \dots \dots \quad (1)$$

where the summation has to be extended to all the values of  $\sigma$  given by

$$Z_\sigma = 0 \dots \dots \dots \quad (2)$$

Examples of the method are given in Jeffry's book "operational methods in Mathematical physics".<sup>1</sup> Bromwich<sup>2</sup> has also given examples relating to the transient vibration of strings. We shall here extend these methods to the particular problem of impact of pianoforte hammer upon a taut string. The problem of pianoforte has been the subject of investigation by Helmholtz, Kaufmann<sup>3</sup>, Raman and Banerji<sup>4</sup>, and others including one of the authors. Das<sup>5</sup> has also obtained a solution in terms of pulses as they are reflected from the extremities of the string, while Raman and Banerji have given a solution in the form of a convergent trigonometrical series. The operational methods give both forms of solution. We shall take one typical case, *viz.*, an elastic hammer striking at any point of the string. It will be observed that the solutions are of the

same type as that of Raman and Banerji analysis and Das's functional formulæ.

### §2.

The differential equation of wave-motion in a tacit string is

$$\frac{d^2y}{dt^2} = \frac{c^2 d^2 y}{dx^2}$$

where  $y$  represent displacement of any point of the string, and  $t$  the time, and  $c$  is the transverse wave velocity.

Let  $A$   $B$  represent the string of length  $l$  and the elastic hammer strikes at the point  $C$ .  $A C = \alpha$ ,  $C B = \beta$ . Since the velocity and displacement are every-

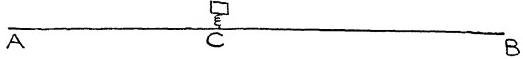


Fig. 1

where zero except at the point  $C$  at time  $t=0$ , the subsidiary equation is

$$\frac{d^2y}{dx^2} = \frac{\sigma^2}{c^2} y \quad . . . . . \quad (3)$$

If the point  $C$  is taken to be the origin of  $x$  axis, then the solution of (3) can be written as

$$y = A e^{\frac{\sigma}{c}x} + B e^{-\frac{\sigma}{c}x}$$

where  $A$  and  $B$  do not depend upon  $x$ . Let  $y_1$  represent displacement over the portion  $CB$ , and  $y_2$  the same over  $CA$ . At  $x=0$ ,  $y_1=y_2$ ; and the displacements should vanish at each extremity, viz.,  $x=-\alpha$ , and  $x=\beta$ . Hence  $y_1$  and  $y_2$  must be of the form

$$y_1 = y_0 \sinh \frac{\sigma}{c} (\beta - x) / \sinh \frac{\sigma}{c} \beta$$

$$\text{and } y_2 = y_0 \sinh \frac{\sigma}{c} (x + \alpha) / \sinh \frac{\sigma}{c} \alpha \quad . . . . . \quad (4)$$

These equations satisfy all the above mentioned conditions. In order to obtain the equation of motion of the hammer we assume that it consists of an effective mass  $M$  backed by an elastic spring of strength  $\mu$ . Further the compression of the spring  $\xi$  is related to the pressure by Hook's law, viz.,

$$p = \mu \xi \quad . . . . . \quad (5)$$

This pressure  $p$  must also be equal to the transverse component of the tension  $T_0$  at  $x=0$ . Hence

$$\begin{aligned} p &= T_0 \left\{ \left( \frac{dy}{dx} \right)_1 - \left( \frac{dy}{dx} \right)_2 \right\} \\ &= T_0 \frac{\sigma}{c} \left\{ \coth \frac{\sigma}{c} \alpha + \coth \frac{\sigma}{c} \beta \right\} \quad . . . . . \quad (6) \end{aligned}$$

from (4). The equation of motion of the elastic hammer is

$$\frac{Md^2\zeta}{dt^2} = -p,$$

and the subsidiary equation is

$$M\sigma^2\zeta = -p + \sigma MV \quad . . . . . \quad (7)$$

where  $\zeta$  represents the displacement of the hammer measured from the beginning of impact, and  $V$  represents the velocity of the hammer when it strikes at  $t=0$ .

Let us now divide the total duration of contact of the hammer with the string into two distinct intervals<sup>6</sup>, *viz.*, (1) Helmholtz régime, and (2) Kaufmann régime. During the former interval there is no displacement of the string, only the hammer felt undergoes compression and then (7) reduces to

$$M\sigma^2\xi = -\mu\xi + \sigma MV_0$$

where  $V_0$  represents the striking velocity of the hammer at  $t=0$ . Hence  $\xi$  is

$$\xi = V_0 \frac{\sigma}{(\sigma^2 + n^2)} \quad \text{where } n^2 = \frac{\mu}{M}$$

and the value of the right-hand side is given by Heaviside's formulæ, *viz.*,  $\xi$

$$\xi = \frac{V_0}{n} \sin nt \quad . . . . . \quad (8)$$

$$\text{and } p = \frac{\mu V_0}{n} \sin nt.$$

Thus during Helmholtz régime the pressure between the hammer and the string is a circular function of time; and this state of affairs continues till two transverse waves are generated which travel one on each side of the striking point. These waves reach the extremities of the string which are supposed to be fixed, hence they are reflected with change of sign. The incident and the reflected waves travel back and forth, and subsequently the displacement of the string is given by (4). When the waves start, the velocity of the striking point of the string and that of the hammer at the same instant are the same; and the transverse component of tension at  $x=0$  is also equal to the pressure due to compression subsisting at the same time.

From these considerations we find at once that

$$V_1 = V_0 \cos nt_1$$

$$\text{and } \tan nt_1 = 2 \left( \frac{\rho}{M} \frac{T_0}{\mu} \right)^{\frac{1}{2}} \quad . . . . . \quad (9)$$

where  $t_1$  is the time as measured from the beginning of impact, and  $V_1$  represents the velocity of the hammer at time  $t_1$ . Kaufmann régime begins when the string is displaced, *i.e.*, from time  $t_1$ , and the total displacement of the hammer  $\zeta$  will be the sum of the compression  $\xi$  and  $y_0$ , hence

During Kaufmann régime the pressure between the hammer and the string is given by (6). Substituting this value in (7) we get

$$y_0 = \frac{V_1}{\sigma + \left( \frac{\sigma^2 T_0}{\mu c} + \frac{c\rho}{M} \right) \left( \coth \frac{\sigma a}{c} + \coth \frac{\sigma b}{c} \right)}$$

$\rho$ =linear density of the string . . . . . (11)

In the case of hard hammer the term  $\frac{\sigma^2 T_0}{\mu c} = 0$ , since  $\mu$  becomes infinite and  $V_1$  equals the impinging velocity  $V_0$  of the hammer, and Helmholtz régime does not exist. The solution will be completed with the help of (1) and (2). Here  $Y_\sigma = 1$  and

$$Z\sigma = \sigma + \left( \frac{\sigma^2 T_0}{\mu c} + \frac{c\rho}{M} \right) \left( \coth \frac{\sigma\alpha}{c} + \coth \frac{\sigma\beta}{c} \right).$$

The imaginary roots of  $Z\sigma=0$  will be given by

$$-\lambda + \left( \frac{c\rho}{M} - \frac{T_0}{\mu c} \lambda^2 \right) \left( \cot \frac{\lambda \alpha}{c} + \cot \frac{\lambda \beta}{c} \right) = 0$$

$\sigma = i\lambda.$  . . . . . (12)

which can also be written in the form

$$\frac{\lambda}{c} \sin \frac{\lambda \alpha}{c} \sin \frac{\lambda \beta}{c} = \left( \frac{\rho}{M} - \frac{T_0 \lambda^2}{\mu c^2} \right) \sin \frac{\lambda l}{c}$$

Where

It will be observed that for hard hammer  $\mu$  is infinity, and (13) becomes the same as that of Raman and Banerji.<sup>7</sup> Since the lowest roots are very small, their approximate values are given by

$$\lambda^2/c^2 = \frac{T_0}{\alpha M} \left| \left( \frac{\beta}{c} + \frac{T_0}{\mu a} \right) \right.$$

which is the same as found by Kaufmann. It is evident from symmetry

that there will be two sets of values for  $\lambda$  since the term  $\left(\frac{\rho}{M} - \frac{\lambda^2}{c^2} \frac{T_0}{\mu}\right)$  is small; for one set  $\lambda\alpha/c$  is nearly equal to

$$\begin{aligned} \frac{\lambda\alpha}{c} &\rightarrow r\pi \left(1 - \gamma_r\right) \\ \text{and for the other set } \frac{\lambda\beta}{c} &\rightarrow s\pi \left(1 - \gamma_s\right) \end{aligned} \quad . . . \quad (14)$$

These relations hold good for  $\frac{T_0}{\mu} \leq 1$ , for larger values of  $\frac{T_0}{\mu} \geq 10$ , all the values have to be found by trial, and the roots depart considerably from the relations (14). Thus the values of  $\lambda$  form an inharmonic series, but the correction term  $\gamma_r$  or  $\gamma_s$  for values of  $\frac{T_0}{\mu} \gtrless 1$ , are small, and then the roots practically form a harmonic series. While for large values of  $\frac{T_0}{\mu}$  the departure from the harmonic relation is considerable. In the present paper the former case  $\frac{T_0}{\mu} \gtrless 1$  is kept in view, and this one is of practical importance since for felt hammers  $\frac{T_0}{\mu} < 1$ . It will be observed that greater the mass of the hammer the nearer will be the values of  $\lambda$  except  $\lambda_1$  to the frequencies of the harmonics of the strings, while the effect of elasticity is in the opposite direction. This can be seen by writing (12) in the following manner.

$$\tan x = \left(\frac{k}{x} - \chi x\right) \left(1 + \frac{\tan x}{\tan \frac{\beta}{\alpha} x}\right)$$

and 
$$\tan x' = \left(\frac{k'}{x'} - \chi' x'\right) \left(1 + \frac{\tan x'}{\tan \frac{\beta}{\alpha} x'}\right),$$

where  $k = \rho\alpha/M$ ,  $k' = \rho\beta/M$ ,  $\chi = T_0/\mu\alpha$ ,  $\chi' = T_0/\mu\beta$ .

The lowest roots  $\lambda_1$  and  $\lambda'_1$  are always less than  $\pi$ , and the second root  $\lambda_2$  or  $\lambda'_2$  may be less or greater than  $\pi$  depending upon the term  $(k/x - \chi x)$ . For instance in the case

$$M=5, \rho=.03, \alpha=30, \beta=70, T/\mu=1, \chi=.033, \chi'=.014, k=.18, k'=.42.$$

$x_1=.45$ , and  $x_2=3.095$  and  $x_r < (r-1)\pi$ , while  $x'_1=.95$ ; and  $x'_2=3.218$ ,  $x'_3=6.26$ .

$$\text{and } x'_{-r} < (r-1)\pi.$$

Further if  $a/l = 1/m$ , then equation (12) shows that it has a series of roots

$$\frac{\lambda}{c} \frac{l}{m} = r\pi$$

that is, if the striking point coincides with a node of the  $m^{\text{th}}$  harmonic of the string, then of the one set of values of  $\lambda$  they are all multiples of  $\pi$  except  $\lambda_1$ , while of the second set there is one root of  $\lambda'$  such that  $\frac{\lambda'(m-1)}{c} l = s\pi$ , and  $s = (m-1)$  hence  $\lambda' m = m\pi c/l$ . Thus in the second set the  $m^{\text{th}}$  root of  $\lambda'$  has the same frequency as the  $m^{\text{th}}$  harmonic of the string. This also follows from the general theorem that a force acting at a nodal point, or a load placed at the same point, does not affect the frequencies of those components which have a node at that point. Further it will be observed that

$$\lambda'^{m+1} > m\pi c/l$$

while

$$\lambda'^{m-1} < m\pi c/l.$$

Having obtained the values of  $\lambda$  we evaluate  $Z'_\sigma$  and substitute in (1) and we get  $y_0$

$$y_0 = \sum \lambda \left[ \left( 1 + \frac{2 T_0 \lambda^2 a}{\mu c^2} / P \right) + \frac{P}{\alpha} \left\{ \alpha \operatorname{cosec}^2 \frac{\lambda a}{c} + \beta \operatorname{cosec}^2 \frac{\lambda \beta}{\alpha} \right\} \right]$$

where  $t'$  is the time measured from the beginning of Kaufmann régime. The value of  $y_0$  has been doubled since  $\sigma = -\lambda i$  is also a solution of  $Z_\sigma = 0$ .

The pressure is given by (6) which after evaluation leads to

$$p = \frac{\rho a \lambda^2 y_0}{P}, \text{ where } P = (k - \chi x^2)$$

or substituting the value of  $y_0$  we get

$$p = 2V_1 \rho c \pi \sum P \left[ 1 + \frac{2\chi x^2}{P} + P \left\{ \operatorname{cosec}^2 \frac{\lambda_r a}{c} + \frac{\beta}{\alpha} \operatorname{cosec}^2 \frac{\lambda_r \beta}{c} \right\} \right] \quad (16)$$

where the summation has to be extended to all the values of  $\lambda$ . The series represented by (16) is an inharmonic series, and the denominator is of the order of  $r$ . For small values of  $\frac{T_0}{\mu} \leq 1$ , the series is practically of the form

$$\left\{ \sum \frac{\sin nx}{n} + \sum \frac{\sin rx'}{r} \right\}$$

hence it forms a convergent series with discontinuities at  $t'$

$$t' = \frac{2\alpha}{c}, \frac{4\alpha}{c}, \frac{6\alpha}{c}, \text{ etc.,}$$

$$\text{and } t' = \frac{2\beta}{c}, \frac{4\beta}{c}, \text{ etc.,}$$

that is, at times when the reflected pulses arrive at the striking point after reflection with change of sign from the ends  $A$  and  $B$  respectively.

At these instants the pressure rises by jumps of magnitude  $\frac{2V_1\rho c}{\chi}$

or  $\frac{2V_1\rho c}{\chi'}$  according to  $t' = \frac{2\alpha}{c}, \frac{4\alpha}{c}, \text{ etc., or } t' = \frac{2\beta}{c}, \frac{4\beta}{c}, \text{ etc.}$  It can be seen on physical grounds that the rise is continuous, the pressure passing through the mean value which the sum of  $n$  terms of the series represents. At the instants  $t' = \frac{2\alpha}{c}, \text{ etc.,}$  the pulses that arrive at the striking point are reflected back again practically without change of magnitude, but with change of sign for any finite mass of the hammer, the result is that the transverse component of tension undergoes a change of magnitude  $2V_1\rho c/\chi$ . This produces an increase of pressure between the hammer and the string of the same amount, but this increase does not take place suddenly, but continuously over an interval  $t_1 = 2 \left( \frac{T_0}{\mu} \frac{\rho}{m} \right)^{\frac{1}{2}}$  during

which the pressure follows a law similar to (8), and the striking point retains a constant velocity with little displacement; the phenomenon takes place in much the same manner as in the beginning of Helmholtz régime. If at any instant the wave reflected from the farther end reaches the striking point, it is also reflected back\*; and a continuous increase of pressure of amount  $2V_1\rho c/\chi$  takes place in the same manner as described above at times  $t' = \frac{2\beta}{c}, \frac{4\beta}{c}, \text{ etc.}$

The phenomenon that takes place at times  $t' = \frac{2\alpha}{c}, \frac{4\alpha}{c}, \text{ or } \frac{2\beta}{c}, \frac{4\beta}{c}$ , is greatly magnified for large values of  $\frac{T_0}{\mu} = 10$  or more.

Equation (16) shows that the magnitude of the components of pressure fluctuates with the values of the denominator to a very large extent. It has been pointed out before that if the striking point coincides with the nodal point of the  $m^{\text{th}}$  harmonic of the string, then the  $m^{\text{th}}$  value

\* See *Phil. Mag.*, Vol. 19, p. 273 (1935).

of  $\lambda$  is the same as the frequency of the  $m^{\text{th}}$  harmonic and  $\sin \lambda_m a/c = 0$ , and the denominator corresponding to this component becomes infinitely large, and the magnitude of the said component is zero, while the next higher component increases in magnitude. As the striking point is shifted to the nodal point of the  $(m-1)^{\text{th}}$  harmonic, the  $(m-1)^{\text{th}}$  component of force vanishes while the  $m^{\text{th}}$  component rises considerably in intensity.

Fig. (2) shows a graphical representation of pressure with time for  $\frac{\alpha}{l} = \frac{30}{100}$  and  $\frac{\beta}{l} = \frac{70}{100}$ .

mass of hammer 5 grms.,  
 $T_0 = 1$ . It has been  
 pointed out before that  
 the pressure components  
 form an inharmonic  
 series, hence in finding  
 out the value of the sum  
 of the series (16), it is  
 evident that a fairly  
 approximate value will

be obtained if only ten or eleven components are summed up, since  
 in the summation the effect of one high frequency component cancels  
 that of another. In drawing the graph only eleven components have  
 been considered; of these the first one is most prominent which has  
 the lowest frequency, while the rest with the exception of the fifth  
 forms practically a harmonic series. The graph shows fluctuations at  
 $\frac{ct}{\alpha} = 2, 4, 6, \text{etc.}$ , and also at  $\frac{ct}{2\beta} = 1$ . In the present case the additional  
 fluctuation due to the arrival of the pulse from the farther end after  
 reflection happens at  $ct = 4.67\alpha$ . This graph may be compared with the  
 oscillographic record of pressure. *Proc. Roy. Soc. Vol. 108, p. 248 (1925).*

### § WAVE SOLUTION

The present section will be devoted for the determination of  $y_0$  in terms of pulses which are reflected from the fixed ends of the string. It has been assumed that the end  $B$ ,  $x=\beta$ , is much farther than the end  $x=-\alpha$ ; we rewrite equation (11) in the form

$$y_0 = \frac{V_1 \alpha / c}{\frac{\alpha \sigma}{c} + \left( \frac{\rho \alpha}{M} + \frac{\alpha^2 T_0 \sigma^2}{\alpha \mu c^2} \right) \left( \frac{1 + e^{-2\sigma\alpha/c}}{1 - e^{-2\sigma\alpha/c}} + \frac{1 + e^{-2\sigma\beta/c}}{1 - e^{-2\sigma\beta/c}} \right)}$$

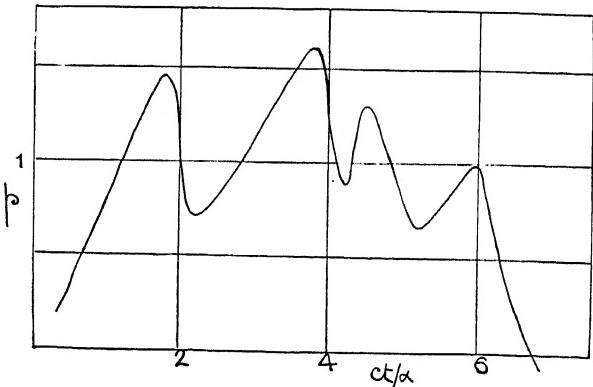


Fig. 2

Put  $\sigma' = \frac{\sigma\alpha}{c}$ , and  $P = \frac{\rho\alpha}{M} + X\sigma'^2$ , and expand the denominator treating  $\sigma'$

as an algebraic quantity according to Bromwich rule. Since  $e^{-2\sigma'} < 1$

$$\begin{aligned} \frac{V_1\alpha}{c} \frac{(1-e^{-2\sigma'})^2(1-e^{-2\sigma'\beta/\alpha})}{(\sigma'+2P)} \Bigg\{ & 1 + \frac{\sigma'e^{-2\sigma'}}{\sigma'+2P} + \frac{\sigma'^2e^{-4\sigma'}}{(\sigma'+2P)^2} \\ & + + \frac{\sigma'e^{-2\sigma'\beta/\alpha}}{(\sigma'+2P)} + \frac{\sigma'^2e^{-4\sigma'\beta/\alpha}}{(\sigma'+2P)^2} \Bigg\} \end{aligned}$$

or

$$\begin{aligned} y_0 = \frac{V_1}{(\sigma'+2P)} \Bigg\{ & 1 + e^{-2\sigma'} \left( \frac{\sigma'}{\sigma'+2P} - 1 \right) + \frac{e^{-4\sigma'}}{(\sigma'+2P)^2} \left( \frac{\sigma'^2}{(\sigma'+2P)} - \frac{\sigma'}{(\sigma'+2P)} \right) \\ & + + \frac{e^{-2\sigma'\beta/\alpha}}{(\sigma'+2P)} \left( \frac{\sigma'}{\sigma'+2P} - 1 \right) + + \Bigg\} \end{aligned}$$

In order to interpret each term by Heaviside's rule we have to resolve each one into partial fractions of the form

$$\frac{\sigma}{\sigma+\gamma};$$

let us assume that  $\gamma_1$  and  $\gamma_2$  are the roots of  $\sigma'+2P=0$ , then

$$\sigma'+2P \equiv (\sigma'+\gamma_1)(\sigma'+\gamma_2).$$

After solution into partial fractions we get the following :—

$$1\text{st term } \left[ \frac{1}{\gamma_2-\gamma_1} \left( \frac{1}{\sigma'+\gamma_1} - \frac{1}{\sigma'+\gamma_2} \right) \right]$$

$$\begin{aligned} 2\text{nd term } & \left[ e^{-2\sigma'} \left\{ - \frac{2\sigma'}{(\gamma_2-\gamma_1)^3} \frac{1}{(\sigma'+\gamma_1)} + \frac{1}{(\gamma_2-\gamma_1)^2} \frac{\sigma'}{(\sigma'+\gamma_2)^2} \right. \right. \\ & \left. \left. - \frac{2\sigma'}{(\gamma_1-\gamma_2)^3} \frac{1}{(\sigma'+\gamma_2)} + \frac{1}{(\gamma_1-\gamma_2)^2} \frac{\sigma'}{(\sigma'+\gamma_1)^2} \right\} \right. \\ & \left. - \frac{1}{\gamma_2-\gamma_1} \left\{ \frac{1}{\sigma'+\gamma_1} - \frac{1}{\sigma'+\gamma_2} \right\} \right] \end{aligned}$$

3rd term

$$e^{-4\sigma'} \left[ \left\{ \frac{-3(\gamma_2+\gamma_1)}{(\gamma_2-\gamma_1)^5} \frac{\sigma'}{\sigma'+\gamma_1} + \frac{(\gamma_2+2\gamma_1)}{(\gamma_2-\gamma_1)^4} \frac{\sigma'}{(\sigma'+\gamma_1)^2} - \frac{\gamma_1}{(\gamma_2-\gamma_1)^3} \frac{\sigma'}{(\sigma'+\gamma_1)^3} \right\} \right]$$

$$\begin{aligned} & \left. -\frac{3(\gamma_1 + \gamma_2)}{(\gamma_1 - \gamma_2)^5} \frac{\sigma'}{(\sigma' + \gamma_2)} + \frac{(\gamma_1 + 2\gamma_2)}{(\gamma_1 - \gamma_2)^4} \frac{\sigma'}{(\sigma' + \gamma_2)^4} - \frac{\gamma_2}{(\gamma_1 - \gamma_2)^3} \frac{\sigma'}{(\sigma' + \gamma_2)^3} \right\} \\ & - \left\{ \frac{-2}{(\gamma_2 - \gamma_1)^3} \frac{\sigma'}{(\sigma' + \gamma_1)} + \frac{1}{(\gamma_2 - \gamma_1)^2} \frac{\sigma'}{(\sigma' + \gamma_1)^2} \right. \\ & \quad \left. - \frac{2}{(\gamma_1 - \gamma_2)^3} \frac{\sigma'}{(\sigma' + \gamma_2)} + \frac{1}{(\gamma_1 - \gamma_2)^2} \frac{\sigma'}{(\sigma' + \gamma_2)^2} \right\} \end{aligned}$$

The  $n^{\text{th}}$  term of the series is of the form

$$e^{-4\sigma'n} \left[ \frac{\sigma'^n}{(\sigma' + \gamma_1)^{n+1}} \frac{1}{(\sigma' + \gamma_2)^{n+1}} - \frac{\sigma'^{n-1}}{(\sigma' + \gamma_1)^{n-1}} \frac{1}{(\sigma' + \gamma_2)^{n-1}} \right]$$

$$\text{Write } \frac{\sigma'^n}{(\sigma' + \gamma_1)^{n+1}} \frac{1}{(\sigma' + \gamma_2)^{n+1}} = \frac{\sigma' A_1}{(\sigma' + \gamma_1)} + \frac{\sigma' A_2}{(\sigma' + \gamma_1)^2} + \frac{\sigma' A^3}{(\sigma' + \gamma_1)^3} + \frac{\sigma' A_{n+1}}{(\sigma' + \gamma_1)^{n+1}} + \frac{\sigma' n}{(\sigma' + \gamma_2)^{n+1}}$$

$$\text{Put } \chi(\sigma) = \frac{\sigma^n}{(\sigma + \gamma_2)^{n+1}}$$

$$\text{Then } A_r = \chi(\gamma_1)$$

$$\chi'(\gamma_1) = A_{r-1}$$

$$\chi''(\gamma_1) = A_{r-2}$$

$$\chi^{r-1}(\gamma_1) = A_1$$

Thus all the terms can be resolved into partial fractions suitable for interpretation.

The first term gives :—

$$y_0 = \frac{V_1 \alpha}{c} \left[ \frac{1}{\gamma_2 - \gamma_1} \left\{ \frac{1 - e^{-\gamma_1 t}}{\gamma_1} - \frac{1 - e^{-\gamma_2 t}}{\gamma_2} \right\} \right] \quad 0 < t < \frac{2\alpha}{c}$$

Other terms do not appear according to the rule of unit function.

The second term appears from  $t > \frac{2\alpha}{c}$ , which runs thus :—

$$\begin{aligned} & \frac{\alpha V_1}{c} \left[ -\frac{1}{(\gamma_2 - \gamma_1)} \left\{ \frac{1 - e^{-\gamma_1(t-2)}}{\gamma_1} - \frac{1 - e^{-\gamma_2(t-2)}}{\gamma_2} \right\} \right. \\ & \quad \left. + \frac{-2e^{-\gamma_1(t-2)}}{(\gamma_2 - \gamma_1)^3} + \frac{-2e^{-\gamma_2(t-2)}}{(\gamma_1 - \gamma_2)^3} \right] \end{aligned}$$

$$+ \frac{(t-2)e^{-\gamma_1(t-2)}}{(\gamma_2-\gamma_1)^2 \underline{1}} + \frac{(t-2)e^{-\gamma_2(t-2)}}{(\gamma_1-\gamma_2)^2 \underline{1}} \Big]$$

$$\frac{2a}{c} < t < \frac{4a}{c}$$

These terms should be added to the first set to obtain the value of  $y_0$  at any time  $\frac{2a}{c} < t < \frac{4a}{c}$ . The third term appears from  $t > \frac{4a}{c}$ , which is

$$\begin{aligned} & \frac{V\alpha}{c} \left[ \frac{-3(\gamma_2 + \gamma_1)e^{-\gamma_1(t-4)}}{(\gamma_2 - \gamma_1)^5} + \frac{-3(\gamma_1 + \gamma_2)e^{-\gamma_2(t-4)}}{(\gamma_1 - \gamma_2)^5} + \frac{(\gamma_2 + 2\gamma_1)}{(\gamma_2 - \gamma_1)^4} \frac{(t-4)e^{-\gamma_1(t-4)}}{\underline{1}} \right. \\ & + \frac{(\gamma_1 + 2\gamma_2)(t-4)e^{-\gamma_2(t-4)}}{(\gamma_1 - \gamma_2)^4} - \frac{\gamma_1}{(\gamma_2 - \gamma_1)^3} - \frac{(t-4)^2 e^{-\gamma_1(t-4)}}{\underline{2}} \\ & - \frac{\gamma_2(t-4)e^{-\gamma_2(t-4)}}{(\gamma_1 - \gamma_2)^3 \underline{2}} - \frac{-2e^{-\gamma_1(t-4)}}{(\gamma_2 - \gamma_1)^3} - \frac{-2e^{-\gamma_2(t-4)}}{(\gamma_1 - \gamma_2)^3} \\ & \left. - \frac{(t-4)e^{-\gamma_1(t-4)}}{(\gamma_2 - \gamma_1)^2 \underline{1}} - \frac{(t-4)e^{-\gamma_2(t-4)}}{(\gamma_1 - \gamma_2)^2 \underline{1}} + + \right] \end{aligned}$$

These also have to be added to the first and second set of terms to get the value of  $y_0$  at any time  $t > \frac{4a}{c}$ . Thus we find that at times  $t = \frac{2a}{c}, \frac{4a}{c}$ , etc., a new set of terms is added. These epochs correspond to the time when the pulse reflected from the extremity  $x = -a$  (A) reaches the striking point, and each time a reflected arrives a new set of terms is added. Similarly, when  $t > \frac{2\beta}{c}$ , terms corresponding to the reflected pulse from the farther extremity have to be added, and they will be exactly similar to the terms just discussed. These results are similar to those of Das's solution obtained by an entirely different process. The wave solution is not suitable for numerical computation. The object in presenting the above result is simply to show that Heaviside's operational methods lead to both the type of solution in a simple and elegant manner.

### SUMMARY

This paper gives a preliminary account of the applications of Heaviside's operational methods to the problem of vibration of strings generated by the impact of an elastic hammer striking at any point of

the string. It has been shown that Heaviside's operational methods can be usefully applied for determining (1) the pressure between the hammer and the string during contact, and (2) the total duration of contact. It has been found that in the case of an elastic hammer the pressure can be represented as the sum of a trigonometric convergent inharmonic series, which, for a slightly elastic hammer practically forms a harmonic series. If  $\alpha$  and  $\beta$  represent the distances of the ends of the string from the striking point, then the pressure has been found to rise continuously but sharply by an amount  $\frac{2V\rho c}{\chi}$  at intervals  $\frac{2\alpha}{c}, \frac{4\alpha}{c}$ , etc., and also at intervals of  $\frac{2\beta}{c}, \frac{4\beta}{c}$ , etc. It has, further, been found that those pressure components vanish which have a node at the striking point. Heaviside's operational methods also enable us to obtain the solution of the problem in the form of pulses which are reflected from both the extremities of the string, but the solution is not convenient for numerical computations.

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THE ABSORPTION SPECTRA OF THE VAPOURS OF THE  
MONO-OXIDES OF COPPER, IRON, NICKEL, AND COBALT  
AND THE DETERMINATION OF THEIR HEATS  
OF SUBLIMATION

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The oxides and sulphides of the elements forming coloured salts are very interesting compounds with regard to the study of the absorption spectrum of their vapours. The absorption spectra of the oxides and sulphides of several elements have already been studied and it was found that in each case they gave rise to at least two regions of continuous absorption with regions of retransmission in between.<sup>1</sup> It appears, however, that PbS does not agree with the general behaviour inasmuch as it gives rise to band absorption spectra.<sup>2</sup> The difference between the beginnings of these regions of continuous absorption corresponded to the difference between the  $^3P$  and  $^1D$  states of oxygen and sulphur. These results made the earlier investigators think that the binding between the atoms forming the molecule was of the electrovalent type and it dissociated on absorption of light into two atoms, one of them (*e.g.*, O or S) in its various electronic states.

The salts of the transitional group and of the rare earth group are all coloured; so are practically all the sulphides. Colours of the salts of the transitional group have been ascribed to the electrons of the d-shell.<sup>3</sup> The colours of the sulphides cannot, however, be explained in this way as their vapours show no band absorption in the visible. The vapours of the coloured salts show not only a continuous absorption in the ultra-violet but a band absorption in the visible as well. This banded absorption has been ascribed in the case of  $\text{CrCl}_3$  to be due to a change in the state of  $\text{Cr}^{+++}$  ion in which the electrons change over from the anti-parallel position to a parallel one or *vice versa*.<sup>3</sup> The oxides and sulphides should also behave in this way. They should give in addition to the continuous absorption, a banded absorption as well in the visible region.

The continuous absorption would give us a clue about the nature of binding between the atoms forming the molecule, whilst the banded absorption would give an indication whether the electrons of the metal part of the molecule change their direction when light falls on them and what would be the energy involved in such a change.

Practically no work had been done before on the absorption spectra of these compounds either in the form of crystals, or in vapour.

#### EXPERIMENT

The substances investigated were the mono-oxides of Cu, Fe, Ni and Co. Since all of these compounds begin to vaporise at rather high temperatures (about  $1500^{\circ}\text{C}$  or even more), the vacuum graphite furnace of this laboratory was utilized. The oxides were introduced in silica tubes 20 cms. long into the furnace.. The source of continuous radiation was a hydrogen tube run by a 2 KW transformer for the ultra-violet region and a pointolight lamp for the visible region. As the pressure of the vapours of the compounds was very small even at those temperatures the hydrogen tube was run at the lowest current (about 10 m.a.) and kept at a large distance so that the intensity of the continuous radiation reaching the absorbing column was very small. With a small intensity of the continuous radiation it was possible to photograph the absorption spectra of a very small quantity of vapour, though with a long exposure (10 mts.). The photographs were taken with E<sub>3</sub> quartz spectrograph and constant deviation spectrograph for the ultra-violet and visible regions respectively. The plates used were the special rapid plates sensitised by Nujol paraffin for the ultra-violet and panchromatic plates for the visible. The copper arc was used for comparison, but for the red and infra-red a neon lamp was used.

To locate definitely the beginning of absorption, microphotometric record of the plates was taken. As the temperatures at which the substances began to vaporise were very high, the silica tube containing the substance was raised to an intense white heat. Although several diaphragms were used it was difficult to avoid all the light from the interior of the furnace from reaching the spectrograph. A portion of the continuous spectrum due to the hydrogen tube was superimposed by an intense one from the furnace. The continuous spectrum was photographed for different times of exposures (3 mts., 5 mts., 7 mts. and 10 mts). Every time the hydrogen tube was run with the same current, and the furnace heated with an empty silica tube to practically the same temperature as

when the substances were actually put in. Finally, one photograph was taken of the absorption spectra of the substance, the exposure being kept at 10 minutes. For each substance the spot of light of the microphotometer was allowed to run perpendicular to the various continuous and absorption spectra at some known wave length. Such microphotograms were taken at several wave lengths. The absorption coefficient of the vapours was calculated at each wave length and the beginning of absorption was determined by plotting the absorption coefficients at various wave lengths and extrapolating to a value of the absorption coefficient very much equal to zero. The wave length corresponding to that was the one at which the absorption began.

#### RESULTS AND CALCULATIONS

Light was found to be cut off in the ultra-violet in each case. In the case of FeO and CuO there was only a single region of absorption. In the case of NiO and CoO there were two regions of continuous absorption with a region of retransmission in between. In the first region the absorption was very feeble and it could be seen visually only with great difficulty. The microphotograms, however, revealed its presence.

As some of these compounds (*e.g.*, NiO and CoO) tend to dissociate into their elements at high temperatures they were vaporised in presence of air, which reduced the dissociation considerably. The oxygen of this air combined with the carbon of the graphite furnace and produced some CO. On some of the plates some of the CO bands were easily discernible. The band heads were at  $\lambda\lambda$  2580, 2560, 2510, 2450, 2410, and 2390. They could be identified with the more intense bands of the Cameron bands of CO.<sup>4</sup> There could not be observed on the plates any line due to the absorption of the vapour of the metal obtained on dissociation of the oxides by heat. This was expected as the vapour pressure of those metals is much too small even at that high temperature to give any absorption line. Physical properties of these compounds such as vapour pressure, melting point or boiling point are not known.

FeO—The long wave length limit of the region of continuous absorption is at 2500 Å (114 Kcals.). The available thermochemical data needed for the calculation of the atomic energy of formation of this molecule are as follows:

<sup>5</sup>Heat of vaporisation of iron at absolute zero=89.025 Kcals.

<sup>6</sup>Heat of formation of FeO=64 Kcals.

Heat of dissociation of O<sub>2</sub> into oxygen atoms=117 Kcals.

NiO—There are two regions of absorption with a region of retransmission in between. The long wave length beginnings of the two regions are 3270 Å (87 Kcals.) and 2380 Å (120 Kcals.). The available thermochemical data needed for the calculation of the atomic energy of formation of this molecule are as follows:

<sup>5</sup>Heat of vaporisation of Ni at 0°K=89.44 Kcals.

<sup>6</sup>Heat of formation of NiO=58.6 Kcals.

CoO—There are two regions of absorption with a region of retransmission in between. The long wave length beginnings of two regions of absorption are 2750 Å (104 Kcals.) and 2100 Å (136 Kcals). The available thermochemical data needed for the calculation of the atomic energy of formation of the molecule are as follows:

<sup>7</sup>Heat of vaporisation of Co=89.3 Kcals.

<sup>8</sup>Heat of formation of CoO=57.5 Kcals.

CuO—The long wave length limit of the region of continuous absorption is at 2410 Å (119 Kcals.). The available thermochemical data for the calculation of the atomic energy of formation of molecule are as follows:

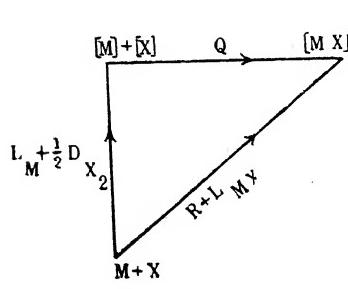
<sup>5</sup>Heat of vaporisation of copper at 0°K=82.06 Kcals.

<sup>9</sup>Heat of formation of CuO=34.9 Kcals.

<sup>10</sup>Heat of vaporisation of CuO=63 Kcals.

The atomic energy of dissociation ( $R$ ) of a diatomic oxide  $MX$  (where  $M$  is the metal constituent and  $X$  stands for the oxygen atom) into normal  $M$  and  $X$  is given by the formula  $R = \frac{N\hbar\nu_1}{J}$  where  $\hbar\nu_1$  is the beginning of absorption and also from the Born cycle

$$R = Q + \frac{1}{2}D_{X_2} + L_M - L_{MX}$$



where  $L_{MX}$ =latent heat of sublimation of solid  $[MX]$ .

$Q$ =heat of formation of solid  $[MX]$  out of solid  $[M]$  and  $X_2$ .

$D_{X_2}$ =heat of dissociation of  $X_2$  into  $X$  atoms.

$L_M$ =heat of sublimation of  $[M]$ .

In the table I the different data and the calculated as well as the observed values of  $R$  are given.

Table I

MX	Q Kcal.	$L_M$ Kcal.	$\frac{1}{2}D_{X_2}$ Kcal.	$L_{MX}$ Kcal.	$\frac{Nh\nu_1}{j}$ Kcal.	R Kcal.
FeO	64	89.025	58.5	...	114	...
NiO	58.6	89.44	58.5	...	87	..
CoO	57.5	88.3	58.5	..	104	..
CuO	34.9	82.06	58.5	63	119	111.5

The agreement between the observed and calculated values of R is good in the case of CuO. In the case of other compounds such a comparison cannot be made as the value of  $L_{MX}$  is not known. Taking the continuous absorption of light by the molecule to bring about its dissociation into M and X, the region of absorption on the red of the spectrum corresponds to the dissociation into normal atoms, whereas others correspond to the dissociation into excited ones. Such an explanation has been found valid for the appearance of the continuous absorption spectra of the oxides Zn, Cd, Pb, alkali earths, etc. Under this assumption we can determine the heat of vaporisation of these compounds from the result of this experiment and other existing thermochemical data. It is given by the relation

$$L_{MX} = Q + \frac{1}{2}D_{X_2} + L_M - R$$

The values of the heats of vaporisation so obtained for the mono-oxides of Fe, Ni and Co are given in the table II.

Table II

Substance	$L_{MX}$ Kcal.
FeO	97.5
NiO	111.5
CoO	101.5

We have, however, more than one region of continuous absorption. The first one we have interpreted to correspond to a dissociation of the molecule into normal atoms, the other we shall interpret as to correspond to a dissociation

into a normal metal atom and an excited O atom. The other region of absorption in the case of FeO and CuO is, if at all, at 2000 Å. The record on the plates is so very feeble at that place that it was difficult to find out if there was any other region of absorption there. The normal state of oxygen is  $^3P$  and the state higher up to this is  $^1D$ . The difference between them is 45 Kcal.<sup>11</sup> The difference obtained in this experiment amounts in every case to about 32 Kcals. The agreement between these

values is far from perfect. We cannot attribute it to the other atom as it is roughly the same for every molecule investigated here. It agrees with the value obtained by Sharma for PbO and seems to have to do something with some peculiarity in the constitution of these diatomic molecules.<sup>12</sup> It may be that the U/r curves of the two unstable molecules M+X(O<sup>3</sup> P) and M+X(O<sup>1</sup> D) are not parallel but have different slopes.<sup>13</sup>

With the data at hand we cannot decide whether the binding between the two constituents is electrovalent of the type M<sup>++</sup>X<sup>--</sup> or of the type M<sup>+</sup>X<sup>-</sup> or even of the covalent type. Such a thing could have been decided if we had known the lattice energy of MX. In absence of this information we cannot come to any conclusion.

The metallic part of these oxides is an element of the transitional group. It has been shown by Saha and Deb<sup>8</sup> that the vapours of the salts of such elements show band absorption. The band absorption was attributed to the action of light on the incomplete 3d shell of the Fe<sup>++</sup> or Fe<sup>+</sup> ion. In the case of Fe<sup>++</sup>, if all the electrons in the normal state are parallel, septet terms are obtained. The action of light would be to turn the spin of one or more of the electrons in the opposite direction giving us a quintet or a triplet term. The spectrum of Fe<sup>++</sup> has not been analysed but from a knowledge of Cr and Mn<sup>+</sup> spectrum we can say that the difference between the corresponding septet and quintet terms in the case Fe<sup>++</sup> would be in the neighbourhood of 15000 cms<sup>-1</sup>. No bands could be observed anywhere on the plates recording the absorption spectrum of FeO, nor were there any on other plates. The reason for the nonappearance of these bands may be that as the furnace was at that time raised to a white heat it radiated a continuous spectrum in the entire visible region of such a great intensity that in spite of the use of diaphragms the plate was covered with such an intense continuous spectrum from the furnace that any bands which would otherwise have appeared on the plate were submerged in it. The nonappearance of the bands does not signify to the fact that Saha and Deb's theory does not apply to these compounds, but to the fact that the experiment has not been conclusive on this point.

#### SUMMARY

The absorption spectrum of the vapours of CuO; FeO, NiO, and CoO was studied. FeO and CuO show only one region of continuous absorption, others have two. Their long wave length beginnings are FeO: 2500 Å; NiO: 3270 Å, 2380 Å; CoO: 2750 Å, 2100 Å; CuO: 2410 Å.

The difference between the beginnings of the two regions of absorption was about 32 Kcals. in each case. This may be due to the oxides dissociating into the metal atom and O (<sup>3</sup>P) and O (<sup>1</sup>D).

The heats of vaporisation for FeO, CoO and NiO have been calculated. They are FeO : 97·5 Kcals., CoO : 101·5 Kcals., NiO : 111·5 Kcals.

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THE ABSORPTION SPECTRA OF THE VAPOURS OF  
THE MONO-SULPHIDES OF IRON, NICKEL,  
COBALT, AND COPPER AND THE  
DETERMINATION OF THEIR  
HEATS OF SUBLIMATION

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In a previous paper<sup>1</sup> it was shown by the author that the action of light on the diatomic oxides of the transitional elements, *e.g.*, Fe, Ni, Co and Cu, is similar to that on other diatomic oxides, *e.g.*, Zn, Cd, alkali earths, etc., which is, in its turn, similar to that on the alkali halides first investigated by Franck and his co-workers.<sup>2</sup> It was found that the vapours of these compounds absorb light continuously from a long wave limit. If we represent any of these compounds by MX where M is a divalent metal and X an element of the oxygen group, then on illumination of the vapour of the oxides by light of suitable frequency, the molecule is dissociated into its constituent atoms. The energy involved may be calculated from the beginning of the continuous absorption. The molecules on absorbing light of proper wave length would dissociate into normal atoms. A good confirmation that the result of dissociation is two normal atoms would be supplied if we could establish from experimental data two more curves for the excited molecules consisting of a normal M-atom with the X-atom in the states  $^1D$  and  $^1S$ .

In such cases, the absorption spectrum would consist of a first cut as mentioned above [indicative of the photo-dissociation of MX into M and normal X ( $^3P$ )], then a retransmission patch followed by a second absorption cut which indicates the decomposition of MX into M and X excited to  $^1D$  state. This may be followed by a retransmission patch indicative of the dissociation of MX into M and X excited to  $^1S$  state. The frequency difference between the different initial cuts will be  $^3P-^1D$  and  $^1D-^1S$  of X approximately. For ferrous and cupric oxides both the second and the third cuts fall outside the quartz region, hence the

absorption due to the dissociation of the molecule into the normal state of oxygen could be found in the case. For the oxides of Ni and Co the third cut falls outside the quartz region, and therefore, only the  $^3P$  and  $^1D$  states of oxygen could be found.

The absorption spectra of the corresponding sulphides are expected to be similar to the oxides. Therefore, as an extension of the previous work some diatomic sulphides were investigated. They were FeS, NiS, CoS, and CuS. The latent heat of sublimation of none of these compounds is known. The present work was undertaken in order to determine the latent heat of sublimation of the substances, and to obtain, in general, an experimental confirmation of the above ideas.

#### EXPERIMENT

The vapour pressure of none of these compounds is known, nor have we any idea of the sublimation points of these compounds. The graphite furnace of our laboratory was used for vaporising these substances. Unlike other furnaces this furnace takes up the desired temperature very quickly—a condition so often necessary when the vapour of the substances diffuse quickly as in the present experiment. The source of continuous spectrum was a hydrogen discharge tube run by a 2 K. W. transformer for the visible, violet and ultra-violet regions and a pointolite lamp for the visible, red and infra-red regions. The Cu arc served for comparison and it was replaced by a neon lamp when the investigations were taken up in the red and infra-red. Special rapid plates sensitised by Nujol paraffin, special rapid and panchromatic plates were used for the respective regions.

All the sulphides evolve sulphur at high temperatures. To avoid this the temperatures were kept as low as possible, but still high enough to give sufficient vapour for absorption. The source of radiation was kept at a large distance so that the intensity of radiation was very much reduced by the time it reached the absorbing column. Although the time of exposure was very much increased by adopting this course, it enabled us to photograph the absorption spectrum of vapours even when their pressures were very small.

Practically all the substances decomposed on heating, and along with the continuous absorption certain bands were also observed. To determine the origin of those bands, the experiment was done once with the furnace filled with nitrogen at 10 cms. pressure and again without filling it with nitrogen but with some trace of air (2-3 mms. pressure) in it.

As the furnace had to be raised to temperatures neighbouring 1000°C it began to emit a bright continuous radiation reaching even up to the near ultra-violet. Diaphragms were used so that only the radiation from the proper source was allowed to fall on the slit of the spectrograph and the radiation from the tube of the furnace was cut off. Even, in spite of this precaution, all the radiation from the furnace could not be cut off and a further reduction of the holes of the diaphragm would have seriously reduced the light-gathering power of the spectrograph and would have considerably increased the time of exposure. The exposure was for 10 minutes—a period during which the entire vapour used to diffuse out of the absorbing passage.

The continuous spectrum was photographed with different times of exposures (3 mts., 5 mts., 7 mts., and 10 mts.) with the empty furnace at the same temperature at which it was kept when the substance was vaporised. To locate definitely the beginning of absorption, microphotometric records of the plates were taken. For each substance the spot of light of the microphotometer was allowed to run perpendicular to the various continuous and absorption spectra at some known wave length. Such microphotograms were taken at several wave lengths. The absorption coefficient of the vapours was calculated at each wave length and the beginning of absorption was determined by plotting the absorption coefficient at various wave lengths and extrapolating to a value of the coefficient very much equal to zero. The wave length corresponding to that was the one at which the absorption began.

#### RESULTS

FeS—No bands were observed in this case both when the furnace was filled up with nitrogen and when a trace of air was left in it. A continuous absorption apparently beginning from 3100 Å appeared. There was also a transmitted patch of light with a second absorption beginning from 2325 Å.

NiS—Bands were observed in this case indicating the dissociation of the compound. When the furnace was filled up with nitrogen the S<sub>2</sub> absorption bands of Christy and Naudé<sup>3</sup> were present. It was found that only the group belonging to the o→n transition appeared strongly on the plates. The extreme ultra-violet bands were not obtained probably owing to the high temperature as Christy and Naudé have mentioned. When, however, the furnace had no nitrogen but a trace of air, the S<sub>2</sub> bands were not developed but only the SO<sub>2</sub> bands of Watson and Parker<sup>4</sup> were obtained. It was thus definitely established that the bands which

were recorded on the plates were due to the dissociation of the sulphur from the compound by heat and had nothing to do with those bands, which are postulated on Saha's theory of the colours of inorganic compounds. There was a continuous absorption beginning from 2810 Å. The retransmission of light was obtained in this case with a second absorption cut beginning from 2170 Å.

CoS—The same bands of sulphur as in the case of NiS were obtained both with the nitrogen filling up the furnace and with some air in it. There was a continuous absorption beginning from 3190 Å. The retransmission of light was obtained in this case with a second absorption cut beginning from 2400 Å.

CuS—In this case, too, the same sulphur bands (cases of NiS and CoS) were noticed. There was a continuous absorption region beginning on the long wave side at 3400 Å. The retransmission of light was obtained with a second absorption cut at 2400 Å.

Table I gives a list of different beginnings of absorption from long wave length limits.

Table I

MS	Beginning of the 1st cut.		Beginning of the 2nd cut.	
	Å	Kcal.	Å	Kcal.
FeS	3100	93	2325	123
NiS	2810	101	2170	132
CoS	3190	89	2400	119
CuS	3400	84	2400	119

## DISCUSSION

Taking R as the heat of dissociation of MX (M being the metal constituent and X being the sulphur atom) into normal M and X the value of R is given by

$$R = \frac{Nhv_1}{J}$$

where  $hv_1$  is the beginning of absorption, and also from a Born cycle.

$$R = Q + \frac{1}{2} D_{X_2} + L_X + L_M - L_{MX}$$

where  $D_{X_2}$  = Heat of dissociation of  $S_2$  into S atoms.

$L_X$  = Heat of sublimation of solid  $[S]_{\text{rhom}}$  to  $S_2$  gas

$Q$  = Heat of formation of solid  $[MX]$  from solid  $[M]$  and solid  $[S]_{\text{rhom}}$

The other symbols are clear.

Now it is known that<sup>5</sup>

$$2 [S]_{\text{rhom}} = S_2 - 29.3 \text{ Kcals.}$$

so that  $L_X = 14.65 \text{ Kcals.};$

and also from Budde's<sup>6</sup> chemical determination and the determination of Christy and Naudé from predissociation of  $S_2$ , the heat of dissociation of  $S_2$  into atomic sulphur ( $D_{X_2}$ ) is 102.6 Kcals. nearly. Prof. R. Samuel of the Muslim University who was kind enough to go through this paper informs me that he has found the value of  $D_{X_2}$  to be 92 Kcals.

The different thermochemical data and the calculated values of  $L_{MX}$  and the observed values of  $R$  are given below in Kcal. The last column shows the values of  $L_{MX}$  calculated on taking Samuel's value.

Table II

MS	$Q^7$	$L_M$	$L_X$	$\frac{1}{2}D_{X_2}$	$R + L_{MX}$	$R = \frac{Nh\nu_1}{J}$	$L_{MX}$	
FeS	23	89.02	14.65	51.3	177.97	93	85	79.3
NiS	20.8	89.44	14.65	51.3	176.19	101.6	74.6	69.3
CoS	19.8	89.3	14.65	51.3	175.08	89	87	81.7
CuS	11.6	82	14.65	51.3	159.55	84	75.55	70.25

In the above calculations it is assumed that the first absorption cut corresponds to the dissociation of the compound into normal atoms. Such an assumption was found to be valid in the case of the sulphides of Zn, Cd, Hg and Pb. In absence of relevant data which would have decided the question regarding the nature of binding of these sulphides we cannot say much about the composition of the stable states of these compounds. We only say that the vapour of the molecule absorbs light of the proper wave length which brings about such a change in its electronic structure that it spontaneously dissociates into two normal atoms—sulphur and the metal atom. That such a state of affairs does take place is substantiated by the presence of the second cut, which we attribute to the photo-dissociation of the molecule into the metal atom and sulphur atom excited to its next level. The difference between the

two cuts ought to give the difference between  ${}^3P$  and  ${}^1D$  terms of sulphur. The experimental values are given in the table III, where  $\Delta$ =Difference between the beginning of the two cuts in Kcals.

Table III

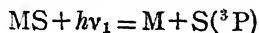
MS	$\Delta$
FeS	30
NiS	30.4
CoS	30
CuS	34

These values agree tolerably well with the value obtained for this very difference by Sen Gupta in the case of ZnS, CdS and HgS. The value as determined from the line spectrum of sulphur has been shown to be 1.41 volts and the average value as obtained in this experiment is 1.36 volts. Thus it appears that the course of potential energy curves for the unstable states of all these sulphides is similar.

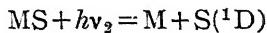
No band absorption different from that of  $S_2$  and  $SO_2$  (which arise from a thermal decomposition of the molecule) is observed in any one of these compounds. The absence may be due to the failure of bands being photographed as there was a strong continuous radiation coming from the heated furnace which might have obliterated any faint bands. Similar explanation had to be offered in the case of the oxides of some of these elements, e.g., Fe, Ni, Co and Cu.

### SUMMARY

1. The absorption spectra of the sulphides of iron, nickel, cobalt, and copper have been studied in the region  $\lambda\lambda 7000-1900$ . The vapours of these substances absorb light continuously from a long wave length resulting in a photochemical dissociation into two normal atoms in accordance with the following photochemical equation.



After the first absorption there is a retransmitted patch and a second absorption corresponding to



2. The heat of vaporisation of these compounds is indirectly determined.

3. The difference  $h\nu_1 - h\nu_2 = 1.31$  volts is attributed to the difference  ${}^3P - {}^1D$  of sulphur.

4. No bands characteristic of the compounds of the transition group has been obtained. Their absence is explained.

## ACKNOWLEDGMENTS

I wish to express my thanks to Prof. M. N. Saha, F.R.S., for his kindness on me. I also thank Principal Ashutosh Mukerji, of the Science College, Patna, and Prof. Kamta Prasad, Head of the Physics Department, for having lent me the use of the microphotometer belonging to the Science College, Patna. My thanks are also due to Prof. R. Samuel who was kind enough to discuss the paper with me.

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THE VARIATION OF VISCOSITY DURING THE COAGULATION OF COLLOID ALUMINIUM HYDROXIDE BY POTASSIUM CHLORIDE SOLUTIONS

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It has been shown in earlier papers<sup>1, 2, 3, 4, 5</sup> that the *slow* coagulation of a number of *hydrophobes* both by electrolytes and oppositely charged colloids does not progress continuously (the course of coagulation being followed by measurement of viscosity), and that usually an initial fall of viscosity was observed soon after the commencement of coagulation. The following experiments were carried out to see as to what support could be given to these findings in the coagulations of a typical *hydrophilic* colloid like aluminium hydroxide.

EXPERIMENTAL

The sol was prepared by the hydrolysis of aluminium acetate and subsequent removal of the acetic acid by careful heating, as recommended by Crum.<sup>6</sup> Except for a faint greyishness it was quite clear in appearance and stable over long time. The colloid content of the sol was 0.48 gm Al<sub>2</sub>O<sub>3</sub> per litre of the coagulating mixture in all the experiments. Viscosity was determined by Scarpa's method with modifications as described previously.<sup>1</sup> The chief advantage in employing this method of measuring viscosity is that no density determinations are necessary. The temperature of the thermostat and the suction applied were kept constant at 35° ± 0.1 and 27° ± 0.03 cms. of water, respectively. Viscosity of the coagulating sol is expressed relative to that of water taken as unity. Equal volumes of the sol kept in the Scarpa's tube and of any of the KCl solutions of the desired strength were allowed to attain the thermostat temperature and then mixed at a known time. Viscosity measurements were continued for about three hours, except when at higher concentrations of the coagulator the system became full of flocculi, earlier. Curves

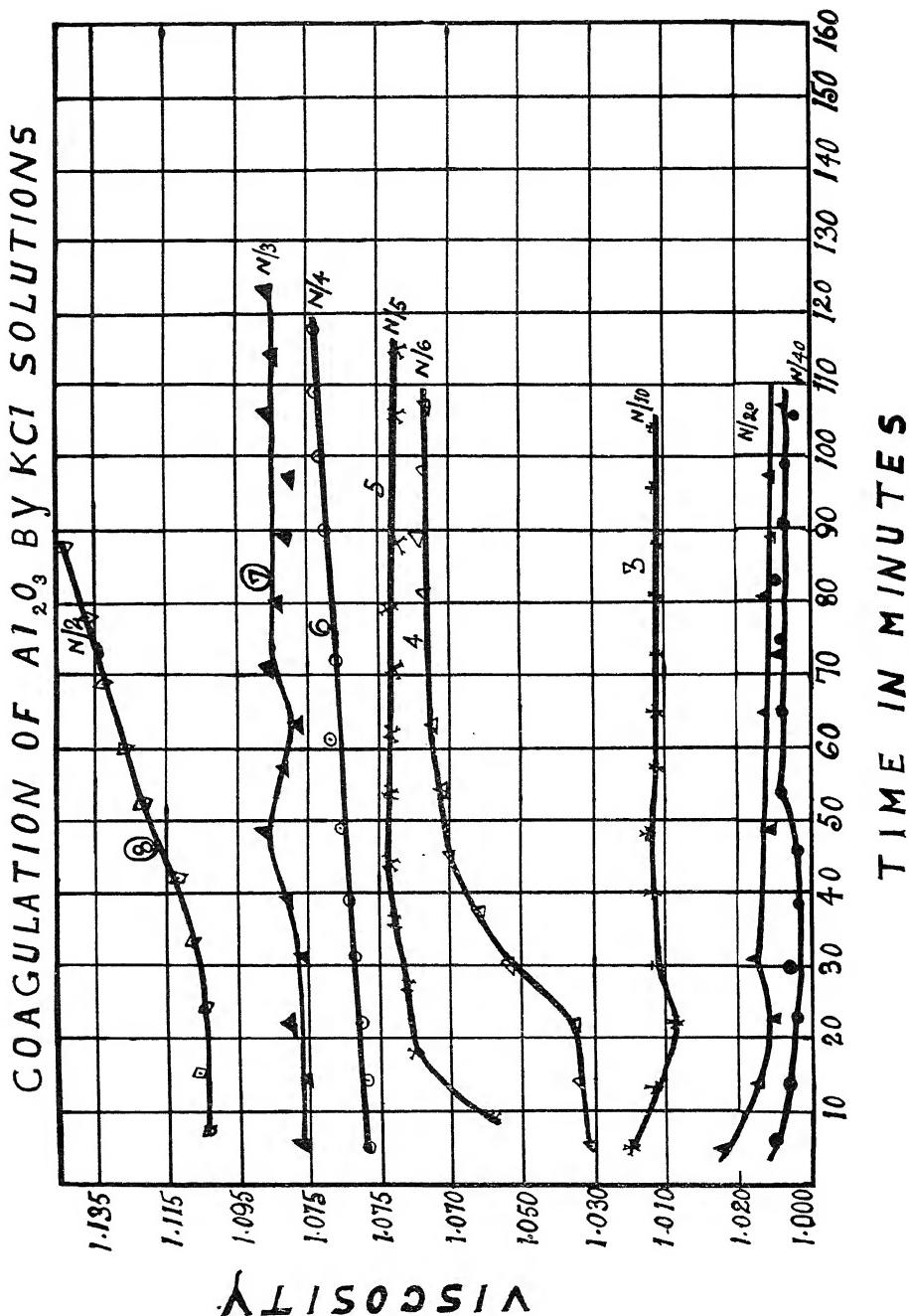


Fig. 1

Nos. 1—8 show the change of viscosity when the concentration of the electrolyte was varied in the range N/40 to N/2 KCl. Data in Table I were obtained from the corresponding curves in Fig. 1. The initial viscosity,  $\eta_i$ , was measured within 5-7 minutes after the introduction of the electrolyte solution.  $\eta_m$  denotes the viscosity at the first minimum on the  $\eta$ -time curve.  $\eta_d$  shows the viscosity diminution at  $\eta_m$  expressed as a percentage of  $\eta_i$ .  $T_{\eta_m}$  is the time in minutes corresponding to  $\eta_m$ .

Table 1.

Curve No.	KCl	$\eta_i$	$\eta_m$	$\eta_d$	$T_{\eta_m}$	REMARKS
1	N/2	1.11	Nil	$\eta$ rises during coagln.		Strong turbidity Heavy flocculation from beginning in about 90 mins.
2	N/3	1.09	"	" "	" "	" " 120 mins.
3	N/4	1.08	"	" "	" "	Turbidity from beginning No sensible flocculation in 2.5 hrs.
4	N/5	1.06	"	" "	" "	" "
5	N/6	1.03	"	" "	" "	" "
6	N/10	1.02	1.01	1% "	22 mins	Slight turbidity " "
7	N/20	1.02	1.01	"	23 "	No sensible turbidity " "
8	N/40	1.01	1	"	23 "	" "

## DISCUSSION

These results show that, as observed previously,<sup>1-5</sup> the progress of coagulation at lowest concentrations of the electrolyte (*cf.* curves 1, 2 and 3) is sensibly discontinuous in the beginning; this includes an initial diminution of viscosity to the extent of about one per cent. and that  $T_{\eta_m}$ , the time corresponding to the occurrence of  $\eta_m$  is unaltered although the concentration of the coagulator has been increased from N/40 to N/10. This indicates, as has been suggested previously<sup>1, 4, 5</sup> on independent evidence, that  $\eta_m$  might not denote a definite stage of coagulation, since the corresponding time is known in general to be markedly susceptible to changes in the electrolytic concentration. It might be added that despite the considerable amount of work reported

in the literature on the coagulation kinetics of this colloid<sup>7, 8</sup>, the occurrence of this initial fall of viscosity does not appear to have been studied quantitatively. The marked frequency of, and conditions favourable to, its occurrence have been indicated in previous papers<sup>1, 2, 5</sup>. It is interesting to mention that Gokun<sup>9</sup>, Woudstra<sup>10</sup>, Farrow<sup>11</sup>, and recently Dhar<sup>12</sup> and coworkers have found in the case of numerous sols that the initial stages of the viscosity-electrolyte concentration curves show a minimum. The time at which the viscosity of the mixture was observed by these workers was *arbitrary*, but in general short. Now,  $T_{\eta_m}$  in these and previous experiments refers to an arbitrary (small), electrolyte concentration on  $\eta$ -time curves; more work is needed to find out the factors which determine its value. It is obvious that the viscosity minimum on  $\eta$ -concentration curves will be greater than equal to, or smaller than  $\eta_m$  depending upon the value of the arbitrary time and the nature of the curve near  $\eta_m$ . Considering particularly the diminution of viscosity on the addition of small quantities of electrolytes, Dhar<sup>12</sup> has suggested a general explanation based chiefly on (*i*) preferential absorption of *like* ions, producing an increase of the charge, and therefore (*ii*) a decrease in the micellar hydration and the viscosity. Now, it has been observed that in a series of coagulations of colloid ferric oxide<sup>8</sup> the viscosity decreases markedly throughout the progress of the coagulation. This is contrary to the requirements of the above explanation according to which the diminution of micellar charge during coagulation should have increased the hydration and therefore the viscosity. An overall decrease of viscosity during coagulation has been observed recently in a large number of coagulations with other sols<sup>4, 2</sup>. It would appear therefore that more experimental work is needed to obtain a *general* explanation of the initial viscosity diminution.

The chief result observed by Freundlich and Ishizaka<sup>7</sup> and by Gann<sup>8</sup> in the coagulations of the  $\text{Al}_2\text{O}_3$  sol which is also shown by the curves in Fig. 1 is that (*i*) the change of the nature of the  $\eta$ -time curve with the coagulator concentration and (*ii*) the general occurrence of *autocatalysis*, that is the acceleration of an initial period of slow change. This is well marked in curve No. 8 corresponding to the highest concentration of the coagulator used, *viz.*,  $N/2$ ; the viscosity also shows an appreciable nett rise. The last diminishes, the initial stage of slow increase increases rapidly in duration, and becomes more *discontinuous* as lower concentrations of the electrolyte are used. Precisely similar results were obtained in the coagulation arsenious sulphide by use of varying dilutions of  $\text{KCl}$ <sup>1</sup>.

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EFFECT OF TEMPERATURE ON BORAX SOLUTIONS  
IN THE PRESENCE OF POLYHYDRIC SUBSTANCES  
AND ORGANIC ACIDS

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Several attempts have been made to study the effect of temperature on a solution of sodium borate. Rose<sup>1</sup> observed that a solution of borax which has been made feebly acidic reacts alkaline when diluted with hot water. Donath and Mayrhofer<sup>2</sup> observed a similar behaviour when the solution was heated. Shelton<sup>3</sup> concluded from conductivity measurements of borax solutions containing extra quantities of boric acid that the hydrolysis of borax into sodium hydroxide and boric acid increases on dilution with water and with rise of temperature.

Dunstan<sup>4</sup> also observed that a solution of borax rendered acidic by the addition of polyhydric alcohols and sugars becomes alkaline when it is largely diluted with water and when its temperature is raised; in the latter case the solution becomes acidic again on cooling. Meldrum and Thakore<sup>5</sup> studied Dunstan's observation (*loc. cit.*) and found that the volume of borax solution containing phenolphthalein required to give the same pink tint with constant amount of the polyhydric substance decreases as the temperature is raised and that the volume-temperature graph is a straight line. The author has extended Meldrum and Thakore's observations over a wide range of temperature to several other polyhydroxy substances and weak acids.

EXPERIMENTAL

Water free from carbon dioxide was used throughout. Sodium hydroxide solution was prepared by the method of Cornog<sup>6</sup> and was diluted to 0'192, 0'1, 0'05, and 0'025 N. Borax solution was prepared, using recrystallised borax, so as to be 0'2, 0'1, 0'05 and 0'025 N, the N solution being supposed to contain  $1/2 \text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$  per litre. The indicator was

prepared by dissolving phenolphthalein, "extra pure," (1.g.) in absolute alcohol (100 c.c.); this solution (0.3 c.c.) was added to the sodium hydroxide solution, and borax solution, (100 c.c.).

The method of work was to put the substance, a sugar or an acid, in a Nessler tube : the solution—sodium hydroxide, or borax, coloured by phenolphthalein—was added until a pink tint was just perceptible : the temperature of the solution was read. This pink colour was taken as the standard. In observing the effect of temperature an experiment was made in a second Nessler tube with the same amount of substance and with a different amount of solution. If the solution was added in smaller amount, the temperature was raised until the pink colour was strong ; or, the solution having been added in excess, the tube was cooled until the colour vanished ; the tube and the standard were compared and the temperature of each solution was read when both had the standard tint.

The behaviour of several substances such as lactose, mannitol, benzoic, salicylic, vanillic and phenylacetic acids with solutions of borax of different concentrations has been studied with change in temperature. Only representative results obtained with mannitol and salicylic acid are given in Tables I and II in which the following symbols are used :—

*Q*—the quantity taken of the sugar or acid ;

*C*—concentration of borax solution ;

*T*—the temperature at which the standard tint appears ;

*x*—the volume of solution in c.c. that gives the standard tint ;

*y*—the calculated number of equivalents (borax or sodium hydroxide)

required to give the standard tint with an equivalent of the substance.

*Table I—Mannitol*

<i>Q</i> <i>C</i>			<i>Q</i> <i>C</i>			<i>Q</i> <i>C</i>			<i>Q</i> <i>C</i>		
0.5 0.2 N			0.3 0.1 N			0.2 0.05 N			0.1 0.025 N		
<i>T</i>	<i>x</i>	<i>y</i>									
68°	12.5	0.910	67°	11.0	0.668	57°	15.0	0.683	64°	11.0	0.501
56°	13.5	0.983	61°	11.5	0.698	49°	16.0	0.728	54°	12.0	0.546
46°	14.5	1.055	51°	12.5	0.759	41°	17.0	0.773	45°	13.0	0.592
38°.5	15.5	1.128	41°	13.5	0.819	34°	18.0	0.819	36°.5	14.0	0.637
30°.8	16.4	1.193	31°	14.5	0.880	29°	18.5	0.842	33°	14.5	0.660
18°	18.0	1.310	18°	15.5	0.941	19°	19.5	0.887	17°.5	16.0	0.728
14°	19.0	1.383	9°	16.5	1.001	11°	20.5	0.933	9°	17.0	0.773

Table II.—*Salicylic Acid*

Q C			0·3 g. 0·2 N.			Q C			0·2 g. 0·1 N.			Q C			0·1 g. 0·05 N.			Q C			0·05 g. 0·025 N.		
T	x	y	T	x	y	T	x	y	T	x	y	T	x	y	T	x	y	T	x	y	T	x	y
86°	14·0	1·288	90°	17·0	1·173	86°	16·5	1·139	74°	16·0	1·104												
71°	14·5	1·335	78°	17·5	1·207	66°	17·0	1·173	49°	16·5	1·139												
54°	15·0	1·380	69°	18·0	1·242	46°	17·5	1·207	27°	16·9	1·166												
43°	15·5	1·426	56°	18·5	1·276	30°	17·9	1·235	10°	17·2	1·187												
31°	16·0	1·472	47°	19·0	1·311	6°	18·5	1·276	...	...	...												
14°	16·5	1·518	28°·6	19·55	1·349	...	...	...	...	...	...												
7°	17·0	1·564	13°	20·5	1·415	...	...	...	...	...	...												

Table III.—*Boric acid—Sodium hydroxide*

Q C			1·0 g. 0·192 N.			Q C			0·5 g. 0·1 N.			Q C			0·3 g. 0·05 N.			Q C			0·2 g. 0·025 N.		
T	x	y	T	x	y	T	x	y	T	x	y	T	x	y	T	x	y	T	x	y	T	x	y
80°	16·0	0·190	72°	14·0	0·174	71°	13·0	0·134	75°	13·0	0·101												
68°	17·0	0·202	62°	15·0	0·186	66°	13·5	0·140	66°	14·0	0·109												
58°	18·0	0·214	52°	16·0	0·198	52°	15·0	0·155	55°	15·0	0·116												
49°	19·0	0·226	42°	17·5	0·211	42°	16·0	0·165	47°	16·0	0·124												
39°	20·0	0·238	37°	17·0	0·217	34°	17·0	0·176	37°	17·0	0·132												
31°	21·0	0·250	32°	18·0	0·223	24°	18·0	0·186	27°	18·0	0·140												
21°	22·0	0·262	23°	19·0	0·234	16°	19·0	0·196	16°	19·0	0·147												
11°	23·0	0·274	13°	20·0	0·248	7°	20·0	0·207	6°	20·0	0·155												

It will be seen from Tables I-III that the volume of sodium borate or of sodium hydroxide solution required to give the standard tint decreases as the temperature is raised for all concentrations of the titrating solution used in this investigation and that the volume-temperature graph is a straight line. This decrease in volume may be due to (i) an increase in the dissociation of sodium hydroxide with rise of temperature, (ii) a change in the hydrogen-ion concentration at which phenolphthalein turns pink, and (iii) a change in the hydrolysis of sodium borate and the sodium salt of the added acid.

Noyes<sup>7</sup> data show that the rise of temperature does not appreciably increase the dissociation of sodium hydroxide and thus rules out the first possibility. As regards the second possibility Kolthoff<sup>8</sup> has shown that the lower limit of the phenolphthalein range is pH 8·3 at 18° C and 7·9 at

100°C. This indicates that smaller [OH'] concentration is required to give the same pink tint with phenolphthalein as the temperature is raised. This effect seems to play a very important part in the observed behaviour of sodium borate and sodium hydroxide solutions.

As the simple system boric acid and NaOH, Table (III), behaves in exactly the same way as the more complicated systems like sodium borate and mannitol, it seems probable that increase in hydrolysis of sodium borate with rise in temperature is the cause of production of pink colour with smaller volumes of sodium borate. Previous investigators have thought that the simple behaviour of more complicated systems like sodium borate and sugars is to be ascribed to the peculiar behaviour of the complexes, but here it is shown that the behaviour of complex systems like sodium borate and mannitol can be due simply to a change in hydrolysis of sodium borate with temperature. Before a definite explanation for the linear relationship mentioned in this paper can be given it is necessary to measure (i) the effect of temperature on the hydrogen-ion concentration of solutions of borax and (ii) the dissociation constant of boric acid, with rise of temperature.

If the straight line of the y-T curves in the case of boric acid-sodium hydroxide (Table III) be produced to meet the axis of temperature, one arrives at a temperature when phenolphthalein will turn pink with boric acid without the addition of sodium hydroxide. It is interesting to note that pink colour is observed when boric acid is heated to 186°C with a small amount of phenolphthalein.

The study of this subject is being continued.

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CHEMICAL EXAMINATION OF THE BARK OF *TERMINALIA ARJUNA* BEDD. PART I. THE ISOLATION OF ARJUNIN.

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*Terminalia Arjuna* (N. O. Combretaceæ) called Arjun in Hindi and Bengali and Kukubha in Sanskrit is a plant used in Indian medicine for a very long time. It is a large deciduous tree attaining 60-80 feet in height. The bark is 1/3 inch thick, smooth, pinkish grey, the old layers peeling off in thin flakes. It is common in the sub-Himalayan tracts of the United Provinces and Deccan.<sup>1</sup>

The bark and its preparation are reputed to have a distinct stimulating action on the heart from times immemorial. Sanskrit writers consider it to be tonic, astringent and use it in heart diseases, contusions, fractures, ulcers, etc. A decoction of the bark is used as a wash in ulcers and chancres.<sup>2</sup> Some of the Western medical practitioners believe in its efficacy and use it as a cardiac tonic. In 1909 Ghoshal<sup>3</sup> studied the physiological and therapeutic action of the drug. According to him the drug acts as a cardiac stimulant and tonic, increasing the force of the beats of the heart, slowing their action, but never completely stopping it. It acts as a powerful haemostatic, only drawback, according to him is the rise in the blood pressure. He also recommended it as a di-uretic. He advocated its use as a valuable remedy in heart diseases. Chopra and Ghosh<sup>4</sup> in 1929 mentioned that the drug produces no stimulating effect on the heart such as that produced by the digitalis or caffeine groups of substances, nor it has any marked di-uretic properties; but very recently in 1930, Caius, Mhaskar and Issac,<sup>5</sup> who made an elaborate and detailed study of all the varieties of *Terminaliae* met with in India reported that they had di-uretic properties and some had both di-uretic and cardiac stimulating effect.

Regarding the chemical composition of the drug there appears to be much confusion. Hopper<sup>6</sup> in 1891 reported that the bark contains 34 p. c. of ash consisting almost of pure calcium carbonate. Ghoshal<sup>3</sup> found it to contain the following substances: sugars, tannins, colouring matters, a body of the nature of glucoside and carbonates of sodium and calcium. Chopra and Ghosh could not find any alkaloid or glucoside,

but reported the presence of an organic acid of high melting point, a phytosterol, an organic ester and some colouring matter. Ram and Guha<sup>7</sup> confirmed the presence of two organic acids and a phytosterol. Caius and co-workers also could not detect the presence of any alkaloid or glucoside. These workers reported the constituents of the ash from fifteen varieties of *Terminalia* studied by them. Chopra and Ghosh (loc. cit.) or Ram and Guha did not give any melting point or other data in support of their arguments regarding the chemical nature of the constituents claimed to have been isolated by them from this important drug.

In view of the fact that so much confusion exists regarding the chemical composition of this plant, the present authors were tempted to put it to a thorough investigation and to isolate the active principle responsible for its therapeutic value as a powerful tonic and di-uretic. Since Chopra and Ghosh (l. c.) had already tried the petroleum ether, alcohol and aqueous extracts of the plant we deemed it proper to extract it with some other solvents. The present investigation has revealed the presence of a colourless crystalline principle, for which the name 'arjunin' is suggested (0.2%) from the benzene extract of the plant.

Arjunin is acidic in nature since it dissolves with effervescence in dilute sodium bi-carbonate solution, and gives a faint red colour with litmus. On continuous boiling with sodium bi-carbonate an insoluble sodium salt is thrown down. It also forms a deep green colour with ferric chloride, forms di-acetyl and di-benzoyl derivatives and hence contains two phenolic hydroxy groups. A penta-nitro-derivative has also been prepared.

Probably arjunin is the aglucone of a glucoside present in the plant claimed to have been isolated by Ghoshal from the benzene extract, and which hydrolyses in the process of isolation.

#### EXPERIMENTAL

An authentic sample of the bark was collected from the neighbourhood of Allahabad in the months of January and February. It was dried in the sun for about a week whereby it lost about 40% of moisture. The dried bark was then finely crushed in an iron mortar, whereby a greyish, brown powder was obtained. On complete ignition of the bark in a porcelain dish, there was left about 28.9% of a dirty white ash. The following elements or radicals were detected in the ash:—

Potassium, sodium (traces), aluminium, calcium, magnesium (traces), silica, carbonates, phosphates, chlorides and sulphates.

In order to get an idea about the soluble portions of the drug 20 grams of the powdered stuff was successively extracted in a Soxhlet's extraction apparatus using different solvents when the following amounts of extract dried at 100°C were obtained.

*Benzene Extract.*—4·10%. An yellowish green extract containing some solid stuff suspended in it. It gave a green coloration with ferric chloride; reduced Fehling's solution readily, and gave a lead salt with lead acetate. No reactions for alkaloids were obtained.

*Chloroform Extract.*—1·00%. A pale yellow-coloured extract was obtained, containing nothing of much interest. No reactions for alkaloids were obtained.

*Ethyl Acetate Extract.*—3·2%. A light brown-coloured extract was obtained containing a dirty white stuff crystallising from it. The extract gave a lead salt with lead acetate, and a light green colour with ferric chloride. The crystalline stuff on recrystallisation melted at 174°C.

*Aqueous Extract.*—13·21%. A dark red coloured extract consisting mostly of tannins, sugars and colouring matters.

For a complete analysis 6 Kilograms of the powdered bark was exhaustively extracted with benzene in a big extraction flask of 5 litre capacity. The extract which was of a pale greenish yellow colour was collected together and the solvent removed by distillation. On cooling the concentrated extract a brownish white sediment (15 gms) separated which was filtered and washed till a dirty white stuff was obtained. This was dried in a steam oven and powdered. It melted at 180-182°C. It was next refluxed thoroughly with a large volume of petroleum ether, in order to free it from any oily or waxy material. The petroleum ether extract on concentration deposited a dirty white substance in waxy flakes melting at 60-62°C, which was identified to be a wax. The quantity obtained, however, was very small (0·8 g) to permit any purification or detailed investigation.

The wax free arjunin was then dried thoroughly in a vacuum dessicator over fused calcium chloride, and recrystallised from a large volume of benzene when microscopic needles were obtained melting sharp at 192°C (decomp). It could also be crystallised from glacial acetic acid. The recrystallised product (12·4 gms) was then dried in a steam oven.

*Properties of Arjunin:* Arjunin is a colourless crystalline substance having no taste or odour. It is slightly soluble in hot water. In ethyl alcohol, methyl alcohol, pyridine and glacial acetic acid it is readily soluble and less so in acetone, benzene, chloroform and amyl alcohol. In ethyl acetate, petroleum ether, ether and carbon tetrachloride it is

insoluble. With concentrated sulphuric acid a light yellow coloration is obtained which changes to blood red on warming and deep violet on standing. With concentrated nitric acid a light red coloration is obtained which on warming evolves fumes of nitric oxide. With chloroform, acetic anhydride and sulphuric acid it gives a blood red coloration. A violet color is developed with Kellar-Kiliani reaction. It gives a green color with alcoholic ferric chloride. With alcoholic lead acetate no precipitate is formed, but with basic lead acetate a heavy light yellow flocculant precipitate of the lead salt is thrown down. With silver nitrate it gives a white precipitate. It dissolves in alkalies and is probably decomposed on being boiled with it. In a dilute solution of sodium bi-carbonate it dissolves with much effervescence and on being boiled deposits the sodium salt as a white gelatinous mass.

(Found: C 59·80, 59·65; H 6·51, 6·30 M.W. (ebbullioscopic in alcohol, 499, 524, 508; (lead salt) 522;  $C_{26}H_{32}O_{11}$  requires C 60·0; H 6·2, M.W. 520)

A sample of arjunin has been sent to the Pharmacological Department of the King George's Medical College, Lucknow, where a detailed study of its physiological properties will be undertaken.

*The Lead Salt:* (1g.) Arjunin was dissolved in 50% ethyl alcohol and an aqueous solution of basic lead acetate added drop by drop till in excess. The flocculant pale yellow precipitate of the lead salt was formed which was filtered on a pump and washed till free of lead and dried. It was a pale yellow amorphous brittle mass (Found Pb 44·1%  $C_{26}H_{28}O_{11}Pb_2$  requires Pb 44·5%).

*The Silver Salt:* (0·5 g.) Arjunin was dissolved in dilute alcohol and a concentrated aqueous solution of silver nitrate added gradually till the precipitate was no longer formed. The flocculant white silver salt formed was filtered washed free of silver and dried. It was dirty greyish white in appearance. (Found Ag 46·1%  $C_{26}H_{28}O_{11}Ag_4$  requires Ag 45·5%).

*The Sodium Salt:* Arjunin (0·5 g.) was dissolved in an aqueous solution of sodium bi-carbonate. Great amount of effervescence took place and the stuff went into solution. On further warming it in a water-bath, the sodium salt was thrown down as a brown gelatinous mass. It could not, however, be obtained in a state of sufficient purity for analysis.

*Di-acetyl arjunin:* 1 gm. arjunin, 50 c.c. of acetic anhydride and a little fused sodium acetate were refluxed over a sand bath for about four hours. The melt on cooling was added into a large volume of water, when the acetyl derivative separated as an amorphous mass. It was filtered washed thoroughly and dried in vacuum over fused calcium chloride. On crystallisation from alcohol, small flakes were obtained

melting at 103°C (Found C 59.15; H 6.00  $C_{30}H_{36}O_{13}$  requires C 59.61; H 5.96%).

*Di-Benzoyl arjunin:* Arjunin (1g.) was dissolved in (50 c.c.) pyridine and Benzoyl chloride (10c.c.O) added gradually with constant shaking. When the whole of benzoyl chloride had been added the mixture was rapidly shaken for about two hours. It was then poured in water whereby an oil separated at the top. This oil on keeping under water for a long time solidified to a hard vitreous mass. On crystallisation from ethyl alcohol well defined small needles were obtained melting at 207°C (Found C 65.5 H 5.65;  $C_{40}H_{40}O_{13}$  requires C 65.8; H 5.49%).

*Pentanitroarjunin:* Arjunin (0.8g.) was dissolved in warm concentrated nitric acid (Sp. gr. 1.08) with gradual stirring. When the solution was complete it was refluxed over a sand bath for half an hour. Copious fumes of nitric oxide were evolved and a gelatinous sticky mass separated. On cooling the mixture and repeatedly washing it with hot distilled water the nitro derivative was obtained as an orange coloured brittle mass. It was then crystallised from glacial acetic acid, whereby pale yellow plates were obtained melting sharp at 118°C (Found N 9.62  $C_{26}H_{27}O_{21}N_5$  requires N 9.4%).

Further work on this plant is in progress.

#### ACKNOWLEDGMENT

One of us (R.R.A.) is highly indebted to the Kanta Prasad Research Trust of the Allahabad University for a scholarship which enabled him to investigate this problem.

#### SUMMARY

From the benzene extract of the bark of *Terminalia arjuna* Bedd., an acidic principle has been isolated called 'arjunin' m.p. 192°C  $C_{26}H_{32}O_{11}$ . The lead, silver and sodium salts, the di-acetyl, di-benzoyl and penta nitro derivatives have been prepared.

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CHEMICAL EXAMINATION OF GLYCOSMIS PENTAPHYLLA  
AND THE CONSTITUTION AND SYNTHESIS OF ITS  
ACTIVE PRINCIPLE

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*Glycosmis Pentaphylla* or *Limonia Pentaphylla* is a common roadside shrub found everywhere in eastern Bengal. Its Sanskrit equivalents are: आस्वशाखोदः and बद्रु, and in Bengali it is commonly known as *Ashseora* or *Mathkila*. Its stems are largely used as tooth brush in eastern Bengal on account of their fibrous nature and slightly astringent bitter taste. Its constant use not only makes the teeth clean but also prolongs their durability. In well-known books on Indian medicinal plants like "The Indian Medicinal Plants" by Kirtikar and Basu, or "The Pharmacographica Indica" by Dymock, the plant is not mentioned along with other medicinal plants of India probably on account of the fact that the plant is practically localised in the eastern parts of Bengal, but some of its medicinal properties are well known even to illiterate women of that country. The bitter juice of the leaves of this plant is very widely used by them for fever, liver complaints and intestinal worms, particularly in the case of children. Occasionally the stem and the root of this plant are used on ulcers with good results. The leaves of this plant are good antidotes for eczema and other skin diseases. Its leaves made into a paste with a bit of ginger are applied over the affected part of the skin, and sometimes the paste of the leaves alone is applied over the naval for worms and for disorders of the bowels. The different Sanskrit names of the plant as also some of its important medicinal properties as given in the famous Kaviraji book compiled by Madan Pala are as follows:

बद्रश्चास्वशाखोदः सपित्तकफ्नाशनः ।  
वातलश्च कृमीन् हन्ति पाण्डुताज्वरकामलान् ॥

which means that the plant known as बद्रु and also आस्वशाखोदः is an antidote for wind, cough, rheumatism, worms, anaemia, fever and jaundice.

On account of the fact that the plant has not been fully described yet in any important book on Indian plants, a short description of it has been thought to be appropriate and is given below.

Description of the plant:—

Plant—unarmed shrub. Natural Order—Rutaceæ. Root—tap root. Stem—woody, rounded. Leaves—compound exstipulate, imparipinnate.

Leaflets alternate, generally five in number, venation pinnately reticulated. Margin finely serrated, apex acute, shape elliptical, surface smooth on both sides, upper side deep green in colour, under side somewhat lighter. Inflorescence—both axillary and terminal, pubescent panicle. Flower—small white with pubescent bracteoles, bisexual, regular actinomorphic, complete. Calyx—polysepalous, sepals five, inferion, broad at the base but pointed at the apex, hairy. Corolla—polypetalous, petals five, hypogynous, white and gland dotted, imbricated in bud. Androecium—stamens free, 8—10, inserted round the disc, hypogynous, filaments stout at the middle, anther with an apical gland. Gynoecium—Pentacarpellary syncarpous, superior, covered with glands. Ovary—five-celled axile placentation, with one ovule in each cell, style short, stigma simple. Fruit—a fleshy berry, colour reddish when ripe, fleshy mesocarp sweet to taste, only one seed is found to develop. Habitat—sparsely throughout tropical and subtropical Himalaya, upper Assam, Travancore, Malay Archipelago, China, Philippine islands, Borneo, Australia and abundantly throughout eastern Bengal.

On account of the great importance of the plant from the point of view of Indian medicine and particularly because no work has been done on it up to this time, the present investigation was undertaken with a view to subject the plant to a systematic chemical examination. As the result of that investigation it has now been found that the active principle "glycosmin" which is a crystalline glucoside, is present throughout the entire plant in traces only, its greatest concentration being found in the new leaves and buds to the extent of 0·2%, while in mature leaves and soft stems, the percentage varies from 0·08 to 0·1%. Along with glycosmin the active principle, a tannin, a phlobaphene, traces of salicin, and about 2·1% of sugars (both reducing and non-reducing) have been found to be present in the leaves.

Glycosmin on further examination was found to decompose very easily into veratric acid and salicyl-aldehyde on treatment with acid permanganate, and this together with the fact that it gave all the reactions of a glucoside led the present author to surmise that probably

the substance was a veratroyl derivative of salicin, which was found to be quite correct, since on boiling it with saturated baryta, it was quantitatively resolved into salicin and veratric acid. This was further confirmed by the synthesis of the substance by the action of veratroyl chloride on salicin in pyridine solution. The veratroyl-salicin thus obtained was identical in all respect with glycosmin, and the mixed melting point was also the same as that of either of the substances taken separately. Glycosmin therefore is quite analogous to populin isolated from poplar buds and which is the benzoyl derivative of salicin. Although poplar (*N. O. Salicaceæ*) belongs to quite a different natural order of plants than *Glycosmis Pentaphylla*, yet it is quite interesting to see that the buds and leaves of both contain quite analogous products. Another very interesting case of such similar products occurring in nature is afforded by the well-known aconite plant. Thus of the two types of aconite growing in Nepal, *Aconitum Napellus* contains aconitine which is the acetyl-benzoyl derivative of aconine, whereas *Aconitum Specatum* contains bikhaconitine, which is acetyl-veratroyl derivative of aconine.

#### EXPERIMENTAL

*Isolation of glycosmin:* Buds and young leaves of the plant were collected from the Mymensingh district of eastern Bengal during July, and carefully dried in the shade. Some complete plants were also collected for systematic examination. For the extraction of glycosmin, the leaves and buds were further dried at 80°C for a period of five hours. Two kilos of dried and coarsely powdered buds and young leaves were then repeatedly extracted with boiling benzene in a large extraction flask until the chlorophyll and wax were completely removed. The residue was then exhaustively extracted with alcohol and from the extract the solvent was removed by distillation. From the light brown syrup thus obtained a small amount of oily impurities were removed by extraction with petroleum ether. The syrup, on subsequent standing for about a week, deposited a quantity of crystalline matter which was removed by thinning the liquid with chloroform and filtering. The substance thus obtained was crystallised from ethyl acetate, alcohol and 50% acetic acid in succession and finally once more from absolute alcohol. The substance crystallises from all these solvents in large colourless plates containing varying amount of solvent of crystallisation. On quickly cooling a concentrated solution of the substance in various solvents, a transparent jelly is obtained. From all these, the solvent of crystallisation is easily

removed by first drying the substance in the air and then in the vacuum desiccator. It melts at 169°C. (Found, C=58·2, H=5·7;  $C_22H_{26}O_{10}$  requires C=58·66, H=5·77%). The substance is only slightly soluble in water and can be crystallised from large quantities of this solvent in the same form as from organic liquids.

*Isolation of salicin.*—The mother liquor after the isolation of glycosmin, was freed from chloroform and dissolved in alcohol. Alcoholic lead acetate was then added until the dirty yellow precipitate no longer formed. The precipitate was filtered off and to the filtrate alcoholic lead subacetate was next added. This caused the immediate precipitation of a bright yellow crystalline precipitate which was also filtered off. From the first lead precipitate on subsequent decomposition with hydrogen sulphide an impure tannin was obtained and from the second lead precipitate a phlobaphene melting between 156°C—162°C was derived in the same manner. The alcoholic mother liquor after the removal of the lead lakes was freed from lead by passing hydrogen sulphide, and after filtration of the lead sulphide, the filtrate was concentrated to a small volume and allowed to stand, when a further crop of glycosmin crystallised out. On adding water to the mother liquor, a white precipitate was obtained which on crystallisation from boiling water was obtained in glistening white flakes melting at 201°C and was identified to be salicin. The quantity obtained was extremely small, being only about 0·02% by weight of the dry leaves.

*Properties of glycosmin.*—Unlike salicin which is very bitter, glycosmin has only a slightly bitter taste which becomes only apparent after keeping the substance on the tongue for some time. Unlike salicin also in concentrated sulphuric acid it dissolves at first to a colourless solution which gradually assumes a brownish red colour. In strong nitric acid it dissolves to a bright yellow colour. The substance does not reduce Fehling's solution or Tollen's reagent, but both these reagents are rapidly reduced on hydrolysis. On warming the substance with a dilute solution of potassium permanganate acidified with sulphuric acid, a strong odour of salicylaldehyde is evolved and from the mother liquor veratric acid can be easily isolated. The substance is optically active, a 5% alcoholic solution showing a lævorotation of  $[\alpha] D_{25}^{\circ}C = -36^{\circ}$ . The substance is moderately soluble in alcohol, acetone and acetic acid, sparingly soluble in hot water and ethylacetate and pyridine and insoluble in cold water, benzene, ether, petroleum ether and chloroform.

*Decomposition of glycosmin with barium hydrate.*—2g. of glycosmin were boiled under reflux with 200 c.c. of a saturated solution of barium

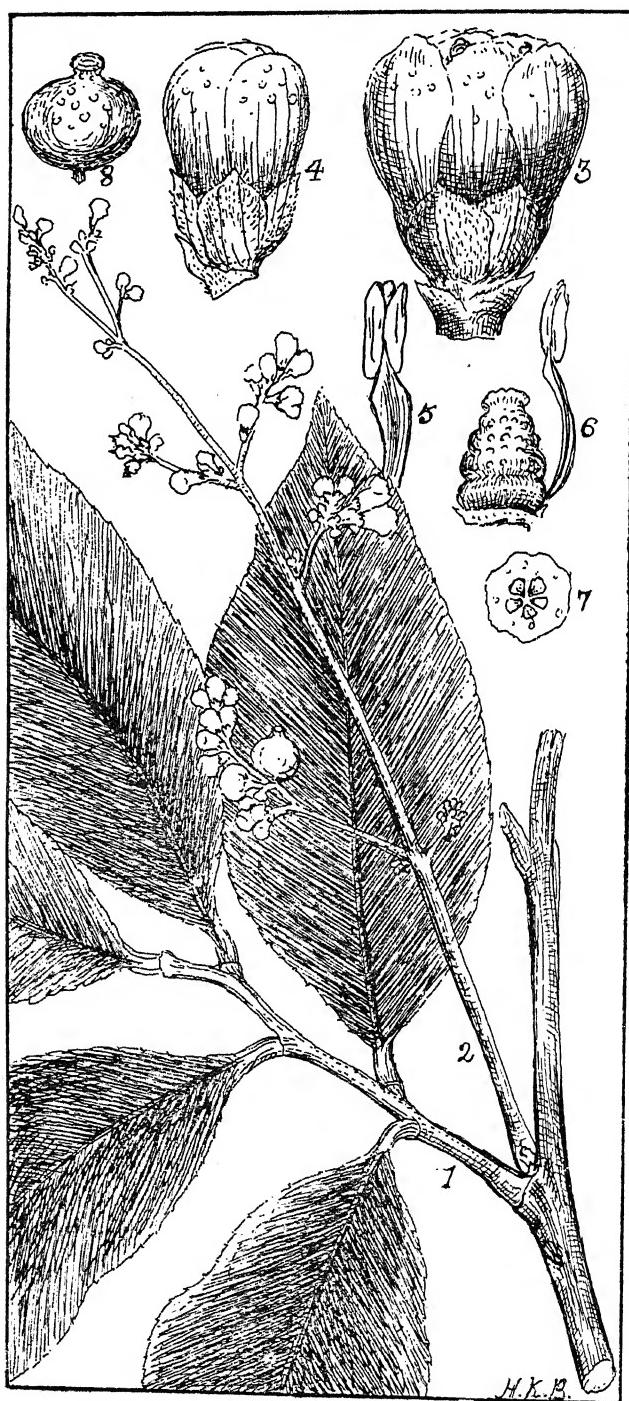
hydrate in water for two hours. The substance gradually went into solution and the clear liquid on cooling deposited glistening white flakes melting at 201°C and which were identified to be salicin. The mother liquor on acidification with dilute hydrochloric acid yielded a heavy white precipitate which on crystallisation from aqueous alcohol was obtained in the form of glistening needles melting at 179°C and was identified to be veratric acid.

*Synthesis of veratroyl-salicin and its identification with glycosmin.*—25g. of veratroyl chloride were gradually added to 20g. of salicin dissolved in 100 c.c. of pyridine at the ordinary temperature. Each addition produced a considerable rise of temperature and the mixture was cooled in cold water before the next addition. After all the veratroyl chloride had been added, the mixture was heated in the water bath for about an hour and then poured into about 500 c.c. of cold water. The resulting white precipitate was filtered off, washed with very dilute sodium hydroxide (to remove any unchanged veratric acid and also salicin) and water and finally crystallised repeatedly from 90% alcohol. The substance was thus obtained in glistening colourless plates which on drying first in the air and finally in the vacuum desiccator melted at 169°C and the melting point was not lowered on admixture with glycosmin in varying proportions. It had all the properties of glycosmin and in fact both the substances were absolutely identical with one another. (Found C=58·3, H=5·8;  $C_{22}H_{26}O_{10}$  requires C=58·66, H=5·77%).

The Author wishes to express his indebtedness to Professor Hemendra Kumar Bhattacharya, M.A., Professor of Botany, Ananda Mohan College, Mymensingh, for supplying him valuable information, both botanical and medicinal, with regard to the plant and also for drawing the excellent plate which accompanies this paper. His best thanks are due to Prof. Bhattacharya on account of this.

#### *Reference to plate:*

1. Compound leaf with five alternate leaflets. Dimensions—6" x 2½".
2. Axillary inflorescence panicle.
3. Flower, 5 x 4 mm.
4. Flower-bud, showing imbricate petals, 4 x 2 mm.
5. One stamen, showing another with an apical gland, 4 x 1 mm.
6. Ovary covered with glands. showing the insertion of stamen below the disc on which the ovary is situated, 2 x 1 mm.
7. Cross section of the ovary.
8. Fruit—a fleshy berry.



FURTHER EXPERIMENTS ON THE FIXATION OF  
ATMOSPHERIC NITROGEN IN THE SOIL AND THE  
UTILIZATION OF MOLASSES AS A FERTILIZER

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In recent communications,<sup>1</sup> it has been shown that when sterilized cane sugar and soil are exposed to sunlight in quartz vessels under completely sterilized conditions there is an increase in the ammonia content of the soil. As these results are of considerable importance in understanding the mechanism of nitrogen fixation in the soil, we have carried on further experiments in this line.

The cane sugar, soil and the silica vessels were sterilized in an autoclave for  $2\frac{1}{2}$  hours at 20 lbs. pressure. In each experiment 25c.c. of sterile distilled water were added and the silica vessels were exposed to light, the mouths of the silica vessels were covered with plugs of sterile cotton wool.

The following results have been obtained:—

Exposure to sunlight from 30th April to the 15th July, 1935.

Total exposure for 480 hours.

Treatment	Ammoniacal nitrogen.	Nitric nitrogen.	Total available nitrogen.	Total nitrogen.
Original Soil ...	0·000902 %	0·003684 %	0·004586 %	0·0474 %
Soil 50 gm. + cane sugar 2 gm. + 25c.c. water in 250c.c. flask.	0·001646	0·00396	0·005606	0·04921
Soil 50 gm. + cane sugar 4 gm. + 25c.c. water in 250c.c. flask.	0·00143	0·0035	0·00493	0·0519
Soil 50 gm. + cane sugar 1 gm. + 25c.c. water in a test tube.	0·001422	0·0035	0·004922	0·0509
Soil 50 gm. + cane sugar 4 gm. and 25c.c. water in a test tube.	0·001454	0·00364	0·005094	0·054

The experimental results show, that in all cases when cane sugar and soil are exposed to light under sterilized condition in quartz vessels, there is an appreciable increase in the total nitrogen and ammonia content. It seems, therefore, established that the energy set free from the photo-oxidation of sugars can fix atmospheric nitrogen in the soil.

As molasses is rich in carbohydrates and is practically wasted in Indian sugar factories, further work was continued with molasses.

#### Experiments With Molasses in the Fixation of Nitrogen

Mixtures of molasses and unsterilized soil were exposed to sunlight during the months of April, May and June, 1935, and the carbon, total nitrogen, ammoniacal nitrogen and nitric nitrogen were estimated. The following results were obtained :—

Treatment.	Ammoniacal Nitrogen.	Nitric Nitrogen.	Total Nitrogen (available)	Total Nitrogen.	Total Carbon
Original soil ...	0·000734%	0·0035%	0·004234%	0·0362%	0·4025%

*After 279 hours' exposure*

5 gm. molasses per kgm. soil.	0·00136	0·00412	0·00548	0·036	0·459
10 " " ...	0·00148	0·00412	0·00560	0·036	0·576
20 " " ..	0·00159	0·00412	0·00571	0·036	0·823
40 " " ...	0·00184	0·00412	0·00597	0·0362	1·0651
75 " " ...	0·0022	0·004	0·0062	0·0382	1·3297
100 " " ...	0·002	0·00324	0·00524	0·046	1·986
150 " " ...	0·00104	0·00284	0·00888	0·0492	3·424
190 " " ...	0·00037	0·00224	0·00261	0·0521	4·021

Treatment.	Ammoniacal nitrogen.	Nitric nitrogen.	Total nitrogen (available).	Total nitrogen.	Total carbon.
Corresponding dark covered with glass coated with Japan black.					
10 gm. molasses per kgm. soil.	0·00074	0·00324	0·00398	0·0361	0·5521
20 " " ...	0·000510	0·0031	0·00361	0·0361	0·9021
40 " " ...	0·000414	0·00282	0·00323	0·036	1·1022
<i>After 850 hours' exposure</i>					
5 " " ...	0·000924	0·00456	0·005484	0·0381	0·412
10 " " ...	0·000964	0·00462	0·005584	0·0381	0·542
20 " " ...	0·001166	0·00462	0·005786	0·0382	0·671
40 " " ...	0·00310	0·0042	0·0072	0·0389	0·912
75 " " ...	0·00175	0·0038	0·00555	0·0391	1·213
100 " " ...	0·001462	0·00362	0·005082	0·0472	1·321
150 " " ...	0·001334	0·00304	0·004374	0·0468	2·321
190 " " ...	0·001202	0·0028	0·004002	0·048	3·28
Corresponding dark covered with glass coated with Japan black.					
10 " " ...	0·000842	0·00320	0·004042	0·0372	0·513
20 " " ...	0·000890	0·00316	0·00405	0·0372	0·882
40 " " ...	0·000936	0·00316	0·00409	0·038	1·087

The foregoing results show that the ammoniacal nitrogen goes on increasing up to a limiting value with time of exposure to sunlight. After this period, further exposure to light leads to a decrease in the ammoniacal nitrogen and an increase of nitric nitrogen, but the sum of the ammoniacal and nitric nitrogen is less than that obtained before. This behaviour is due to the loss of nitrogen in the gaseous state caused by the photochemical, thermal and catalytic decomposition of ammonium nitrite formed on the soil surface. This type of denitrification is an important soil process taking place when large amounts of nitrogenous compounds are present in the soil, which is exposed to air and light.<sup>8</sup>

Another interesting point, which has been brought out by the foregoing results, is that the maximum increase of ammonia is attained after a longer exposure to sunlight in those dishes containing larger amounts of molasses than those containing smaller amounts. For example, with 10 gm. of molasses when added to a kilogram of soil, the maximum amount of ammonia formed is reached after 279 hours of exposure to sunlight, whilst with 40 gm. the maximum is reached after 850 hours of exposure.

In order to investigate whether the addition of molasses could be used in the improvement of rice cultivation the following experiments were carried on :—

As rice requires a lot of water and it is easy to submerge the plant root in water when the plant grows in low lands, two ditches measuring 140 square feet were dug side by side and to one of the ditches 11 seers of molasses were added on the 30th April, 1935, and the soil was dug twice a week and was watered.

The following table shows the nitrogen contents of the two ditches before and after the addition of molasses :—

Treatment.	Ammoniacal nitrogen.	Nitric nitrogen.	Total available nitrogen.	Total nitrogen.
Control analysed on 10th May, 1935.	0·000924%	0·003684%	0·004608%	0·0468%
Molassed plot analysed on 10th May, 1935.	0·000996	0·003684	0·00468	0·0498
Control analysed on 25th July, 1935.	0·00086	0·00344	0·0043	0·0464
Molassed plot analysed on 28th July, 1935.	0·001468	0·00466	0·006128	0·0521

Due to heavy shower in the beginning of July a good deal of the nitrogen was lost by leaching. Rice seed was sown on the 17th July, 1935, and at present it is found that the growth of the rice plant is much better on the soil containing molasses than that without it. Similar results were obtained with maize.

It will be interesting to note, that the report on the administration of the Department of Agriculture, U. P., ending on the 30th June, 1934,

contains the following lines regarding the use of molasses as fertilizer in sugarcane.

"Preliminary manurial experiments with molasses failed to yield significant results. Green manure with *sann* increased the yield by over 40%." When the Economic Botanist in charge of Shahjahanpur station was written to, he kindly supplied the following results obtained in Shahjahanpur farm with sugarcane:—

Treatment.	Brix.	% sucrose in juice.	Purity coefficient.	% glucose in juice.	Yield of cane per acre in maund.
Control	17.57	15.90	90.50	0.29	601.0
Molasses 90 maunds per acre before planting.	16.97	16.56	92.15	0.21	653.2
180 ,	17.87	16.38	91.66	0.20	769.0
270 ,	17.47	16.06	91.92	0.21	816.0
Molasses 90 maunds per acre at sowing time.	17.67	16.45	93.10	0.23	575.2
180 ,	17.77	15.57	93.24	0.20	609.0
270 ,	17.77	16.50	92.85	0.20	670.6
Molasses 90 maunds per acre at tillering time.	18.58	17.24	92.79	0.16	625.2
180 ,	18.68	17.28	92.51	0.16	570.4
270 ,	18.48	16.85	91.18	0.20	558.0

The foregoing results show that when the molasses is added before the crop is sown the yield of sugarcane is considerably increased. With 270 maunds per acre of molasses there is an increase of 36% in the yield of sugarcane. We have emphasised in our previous publications that considerable fixation of atmospheric nitrogen takes place in tropical soils and a better crop yield is obtained on the addition of molasses provided the aeration of soil is sufficient. When the aeration is incomplete nitrogen fixation becomes defective, because in fixation energy is necessary and this comes from the oxidation of sugars.

In Java, Hawaii, Cuba, Queensland and other countries, beneficial results with rice and cane sugar on the application of molasses have been reported. As molasses forms acids at first when added to soils, alkaline and *usar* soils are benefited by the addition of molasses.

Molasses as fertilizer in the fixation and conservation of soil nitrogen is in use at the Nyagogra Tea Estate (Assam), in Champaran (Bihar), the Presidency manure work (Madras), Nagaria (Etah), Arbalia demonstration farm (Bengal), Kampiergunj farm (Gorakhpur), Kichha (Naini Tal), and in some farms in Java under instructions from the authors of this paper.

Attempt has been made to fix atmospheric nitrogen by the energy obtained from the induced oxidation of glucose or cane sugar, by passing air in presence of ferrous hydroxide as inductor. Air aspirated through two Woulf's bottles, one containing a solution of ferrous sulphate in sulphuric acid and the other concentrated sulphuric acid in order to remove the oxides of nitrogen and ammonia and to kill the bacteria, was passed through an Erlenmeyer flask containing a weighed amount of glucose or cane sugar and ferrous hydroxide, obtained from one gram of ferrous sulphate and its equivalent amount of caustic potash. After passing 550 litres of air the amount of ammonia formed was distilled off by adding alkali and heating. The distillate was absorbed in dilute sulphuric acid and the ammonium sulphate was estimated colorimetrically by Nessler's reagent. Two Erlenmeyer flasks containing dilute sulphuric acid were placed next to the flask containing the inductor; the last one for the absorption of the ammonia from the atmosphere.

The following results were obtained :—

Grape sugar oxidised = 0.08 gm.

Ammoniacal nitrogen formed = 0.000332 gm.

Cane sugar oxidised = 0.04 gm.

Ammoniacal nitrogen formed = 0.000245 gm.

$$\frac{\text{Grape sugar oxidised}}{\text{Ammonia formed}} = \frac{0.08}{0.000332} = \frac{1000}{4.15}; \text{ efficiency} = 600: 1$$

$$\frac{\text{Cane sugar oxidised}}{\text{Ammonia formed}} = \frac{0.04}{0.000245} = \frac{1000}{6.12}; \text{ efficiency} = 457.5: 1.$$

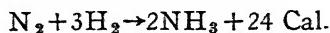
#### **Mechanism of nitrogen fixation.**

There is considerable difference of opinion regarding the mechanism of the fixation of atmospheric nitrogen in the soil. One school believes that ammonia is the first product and the other school holds that

nitrates are first formed. Under both anaërobic and aërobic conditions it is believed that ammonia is the first product of fixation. Glucose has been found to decompose into pyruvic acid and hydrogen under anaërobic conditions according to the following equation



In presence of the nitrogen of the atmosphere and on the soil surface, the hydrogen obtained by the decomposition of the glucose may form ammonia according to the following equation.



In presence of oxygen, that is, under aërobic condition it is difficult to assume that ammonia is also the first product of nitrogen fixation. Because, in presence of oxygen glucose can undergo one or more of the following changes.

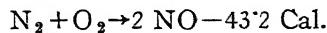
- (1)  $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + 676 \text{Cal.}$
- (2)  $\text{C}_6\text{H}_{12}\text{O}_6 + 4\frac{1}{2}\text{O}_2 \rightarrow 3\text{C}_2\text{H}_2\text{O}_4 + 3\text{H}_2\text{O} + 493 \text{Cal.}$   
oxalic acid
- (3)  $\text{C}_6\text{H}_{12}\text{O}_6 + 1\frac{1}{2}\text{O}_2 \rightarrow \text{C}_6\text{H}_8\text{O}_7 + 2\text{H}_2\text{O} + 199 \text{Cal.}$   
citric acid
- (4)  $\text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \rightarrow \text{C}_6\text{H}_{10}\text{O}_7 + \text{H}_2\text{O} + x \text{Cal.}$   
glycuronic acid
- (5)  $\text{C}_6\text{H}_{12}\text{O}_6 + \frac{1}{2}\text{O}_2 \rightarrow \text{C}_6\text{H}_{12}\text{O}_7 + x \text{Cal.}$   
gluconic acid

The energy obtained from these oxidation reactions has to be utilised in the decomposition of water according to the equation.



for the formation of ammonia.

The direct combination of nitrogen and oxygen forming oxides of nitrogen according to the equation



appears to require less energy than the process leading to the formation of ammonia. Moreover, the nitric oxide can be further oxidised to nitric acid by air and the nitric acid can form nitrates in the soil. The iron compounds, traces of manganese, and copper compounds present in the soil facilitate this oxidation. Moreover, sunlight which falls on the soil surface can also help the oxidation of nitrogen by the oxygen of air. Dhar and Mukherjee<sup>5</sup> have shown that solutions

of nitrates and carbohydrates in presence of sunlight and titania can readily form small amounts of amino acids with copious production of ammonium salts. It is interesting to note that ammonium salts and carbohydrates when exposed to sunlight in presence of titania do not, however, form amino acids for the production of which nitrates have to react with carbohydrates. It is well known that in plants, proteins which are mostly the condensation products of amino acids are only formed when carbohydrates have already accumulated by photosynthesis. The carbohydrates formed by photosynthesis in plants react with nitrates absorbed by plants from the soil and this results in the production of amino acids, proteins, and ammonium salts in the plants. As a matter of fact, Waynick and Woodhouse<sup>6</sup> have obtained evidence of amino acid formation in nitrogen fixation by azotobacter. It is believed that during the first few days of growth of azotobacter, amino acids accumulate and later on proteins increase. In our experiments with pure cultures of azotobacter thriving in mannite medium we have been able to detect amino acids by the valuable ninhydrin test. According to Lathrop<sup>7</sup> several amino acids are of common occurrence in the soil. These amino acids may be obtained either by the hydrolysis of proteins added to the soil as manure or formed by synthesis as already explained. It seems likely therefore, that *in vitro* as well as in the plant and in the soil the nitrate is reduced to ammonia by the action of carbohydrates or other carbonaceous substances with the simultaneous formation of amino acids in small amounts. Hence it appears that nitrate is first produced in nitrogen fixation and the nitrate reacts with the energy-rich materials present in the soil with the formation of ammonium salts and small amounts of amino acids.

A very important fact has been brought out by these researches—that the amount of ammonium salts obtained by fixation depends on the amounts of available and possibly total nitrogen originally present in the soil, to which energy-rich compounds have been added. Thus in our first set of experiments with pure cane sugar when added to unsterile soil and exposed to sunlight, the ammoniacal nitrogen rose to 0'0186 % from 0'00126 % originally present in the soil, which contained 0'00164 % available nitrogen. In the second series of experiments, the ammoniacal nitrogen increased from 0'00192 % to 0'0162 % and the total available nitrogen in the soil was 0'00392.

Similarly with molasses, the fixation was less as it contained some ammonium salts. Our results show that the ammoniacal nitrogen increased from 0'00073 % to 0'00222 % when the total available nitrogen present

in the soil and added with molasses was 0.00433 %. It appears, therefore, that in soils containing a larger percentage of nitrogen, the fixation due to the addition of energy-rich compounds will be less marked. In tropical countries, however, the nitrogen fixation on the addition of energy-rich compounds is likely to be always prominent as the nitrogen content of tropical soil is low. Further experiments in this direction from the bacteriological and chemical viewpoints are in progress.

In publications<sup>2</sup> from this laboratory it has been emphasised that light plays an important rôle in many oxidation processes taking place in the soil and that chemical and not microbiological agencies are active in many of these reactions. Further evidence has been brought forward in this paper in favour of the same view, as our results show that nitrogen fixation can take place in the complete absence of bacteria when sugars are oxidized in presence of sunlight or inductors.

In this connection, the following statements of Corbet<sup>3</sup> are of considerable interest:—

#### **"The photochemical oxidation of ammonia to nitrous acid."**

The recent investigations of Dhar and his coworkers show clearly that nitrite formation can be effected in the absence of micro-organisms.

In the present research, experiments were carried out to determine the extent of the photochemical oxidation of ammonium sulphate and the results obtained by the Indian investigators were confirmed."

"The criticisms advanced by Fraps and Sterges (1935) against the work of Dhar and Gopala Rao are without substance, since in their experiments soil was exposed to the sun in pyrex beakers covered with glass. The writer has confirmed that no ultraviolet radiations of wavelength capable of oxidizing ammonium salts to nitrite can penetrate these materials."

"The depth to which ultraviolet light can penetrate the soil is an important matter in this connection in the tropics. It is believed that photonitrification of ammonium salts is effected by light of the wavelength 3100–2900 Å. The mercury arc emits radiations down to 1800 Å, while the solar spectrum does not penetrate into ultraviolet regions beyond 2900 Å. Nevertheless, the question of penetration of soil by chemically active radiations from sunlight cannot be readily dismissed: Hoerlin (1934) states that the ultraviolet radiation in equatorial latitudes is of different intensity and composition from that in temperate regions."

"It seems evident that the fall in the nitrogen content of the soil to a lower level on subjection to higher temperatures must be ascribed to chemical and not to microbiological agency."

Moreover, O. N. Allen<sup>4</sup> has made the following observation : "Photochemical Nitrification: The work of Rao and Dhar has done much to explain nitrification in tropical areas upon a purely chemical basis. Their results seem to warrant that to a certain extent nitrification is photochemical in nature, the process taking place at the surface of various tropical soils in the presence of certain photosensitizers under the influence of sunlight."

#### SUMMARY

1. When sterile cane sugar solution and sterilised soil are exposed to sunlight in quartz vessels under sterilized conditions, the ammoniacal and total nitrogen are increased.
2. When air freed from bacteria and oxides of nitrogen and ammonia is passed through a solution of glucose or cane sugar mixed with freshly precipitated ferrous hydroxide, appreciable amounts of ammonia are formed.
3. It appears, therefore, that nitrogen fixation can take place in the complete absence of bacteria provided energy is available from the photochemical or induced oxidation of sugars.
4. When molasses is mixed with unsterilized soil and exposed to sunlight, the ammonia content goes on increasing with the exposure up to a limiting value.
5. Molasses when added to soil in the field also increases the ammoniacal and total nitrogen contents of the soil.
6. Molasses has been used as manure in increasing the yield of sugarcane to the extent of 36 %. Rice cultivation is also improved by the addition of molasses to the soil.

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*PHYSALOPTERA ACHARI* N. SP. FROM *CALOTES VERSICOLOR*  
WITH A SHORT NOTE ON ABNORMALITIES IN THE  
GENUS *PHYSALOPTERA*.

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*Physaloptera achari* n. sp.

A number of worms were obtained from the stomach, small and large intestines of *Calotes versicolor* found in Hyderabad Deccan. It is interesting to note that in one case two gravid females were taken out from the rectum while the immature worms were found to be lying in the stomach and the small intestine.

The parasites are slender and attenuated towards both the extremities. The cuticle is transversely striated and is slightly reflected over

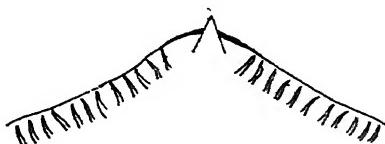


Fig. 1a.—Inner view of lip.

the lips. Each lip is provided with a large pointed external tooth. Round the border of the mouth there is a series of large pointed denticles (Fig. 1a). Externally each lip carries a large subdorsal and subventral papilla.

The females measure from 26-38 mm. in length and 0·59-0·71 mm. in breadth. The vulva opens flush with the surface. In a female 38 mm. long, it lies at a distance of 6·7 mm. from the anterior end. From the common trunk the four uteri take their origin at the same level (Fig. 1b). The eggs are oval, fully embryonated *in utero* and measure 0·049 × 0·027 mm.

The species is named after Dr. S. D. Achar, Superintendent of Serum Institute, Bangalore, S. India.

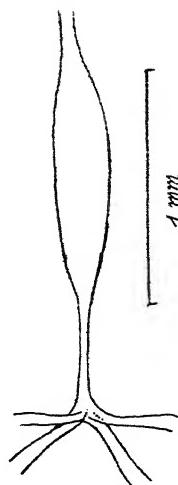


Fig. 1b.—Mode of origin of uteri.

The cervicle papillæ and the excretory pore in a female 38 mm. long, are at a distance of 0·41 mm., and 0·52 mm. respectively, from the anterior end. The œsophagus measures 4·91 mm. in length.

The males measure from 11·17 mm. in length and 0·29-0·38 mm. in breadth. The bursa is voluminous (Fig. 2). The anus is small and transversely oval. Only the anal region is ornamented with tubercles.

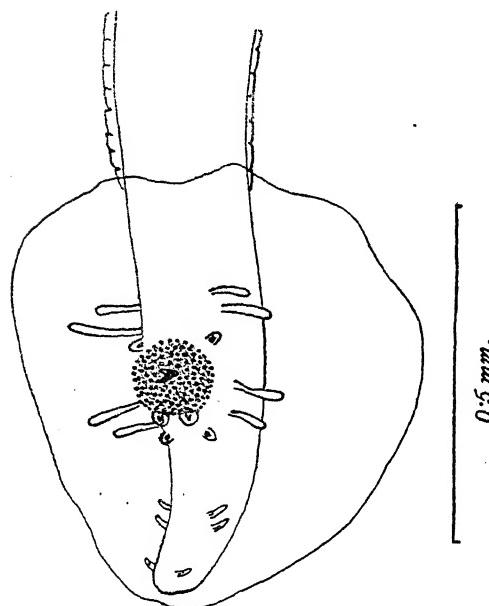


Fig. 2.—Caudal end of *Ph. achari*.

It was not possible to measure the spicules as they were not fully chitinised in any of the four males which were examined. The writer does not attach much importance to the size of spicules in differentiating a species, for, it has been determined that the spicules in different individuals of the same species vary in size. The characteristics of the species of the genus *Physaloptera* should mainly depend upon the size, shape and the arrangement of the pre- and post-anal ventral papillæ. The form of the uteri and the arrangement of the teeth and denticles on the lips should also be taken into consideration.

All the species described from the Australian lizards belong to the Group in which there are four uterine branches originating by dichotomous division of the common trunk. This species differs from them in possessing four uteri which take their origin at the same level, in the arrangement of the ventral papillæ and the structure of the lips.

Of the four pairs of lateral pedunculated papillæ, two are pre- and two post-anal in position. The distance between the pairs 2 and 3 is much more than between the contiguous pairs. There is only a single pair of pre-anal, but there are five pairs of post-anal ventral papillæ. The first and second pairs lie one behind the other. The third and the fourth pair are found near each other just a little behind the middle of the tail. Near the tip of the tail there is another pair of papillæ. All these papillæ possess a short stalk.

### Abnormalities in the Genus Physaloptera

The writer of this paper has observed now and then abnormalities in the size, position and the arrangement of the ventral papillæ in the males belonging to a particular species. In *Ph. paradoxa* (a re-description of this species will be given at a later date) one may notice the displacement of the two pairs of post-anal papillæ lying in the vicinity of the anus (Fig. 3). The specimen is not stretched at all as will be seen from the position of the other papillæ. These post-anal papillæ

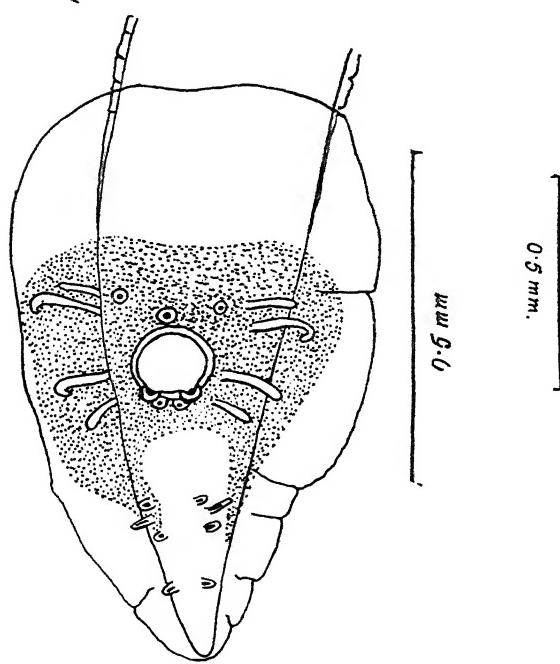


Fig. 3.—Caudal end of *Ph. paradoxa*.

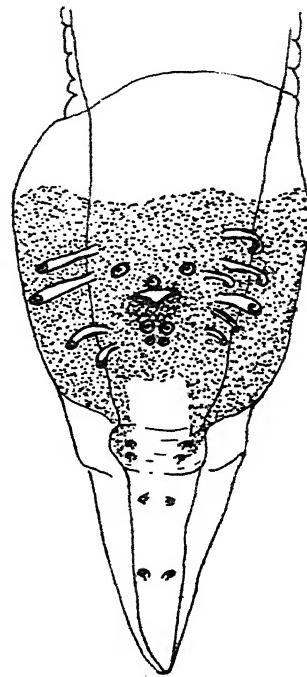


Fig. 4.—Caudal end of *Ph.* species from  
*Varanus Indicus*.

do not lie one behind the other as is the case in the normal specimens. The second pair lies internal to the first pair and are much bigger in size than the former. Figure 4, represents the caudal end of *Physaloptera sp.* recovered from the stomach of *Varanus indicus* described by the writer in a former paper. On the left side there are 6 lateral pedunculated papillæ instead of the usual number of four on each side. This is an interesting case of abnormality. Ortlepp (1922) has also described an abnormal *Physaloptera sp.* from a Bandicoot.

The specimens have been deposited in the Museum of the Zoological Laboratories, Muslim University, Aligarh, U.P., No. 959.

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STUDIES ON THE FAMILY HETEROPHYIDÆ ODHNER, 1911.

Part II—"Four New Parasites of the Genus *Haplorchis* Looss, 1899, from Indian Fresh-water Fishes with a Revision of the Genus."

BY HAR DAYAL SRIVASTAVA

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Communicated by Dr. H. R. Mehra.

Received on January 11, 1935:

**Sub-family—*Haplorchinæ* (Looss, 1899), Poche, 1926.**

Looss in 1899 created this sub-family under the incorrect name *Haplorchinæ* for two new genera *Haplorchis* and *Galactosomum*. The former genus was established by Looss in 1899 for *Monostomum pumilio* Looss, 1896, parasitic in the intestine of *Pelecanus onocrotalus* and *Dist chirinus* Looss, 1896, parasitic in the gut of the fishes *Bagrus bayad* and *B. docmac*. In 1924 Nishigori created the sub-family *Monorchotreminae* for a new genus *Monorchotrema* containing two species—*M. taihokui* and *M. taichui*. Two years later Faust and Nishigori worked out in detail the life-history of the two species of *Monorchotrema* and experimentally showed them to be capable of infecting any bird or mammal, including man. Wittenberg in 1929 transferred the genus *Galactosomum* from *Haplorchinæ* to *Heterophyinæ* Ciurea, 1924, and also suggested the probable identity between the type species of *Haplorchis* and *Monorchotrema* and assigned the latter genus to *Haplorchinæ*. A year later, however, he definitely came to the conclusion that the type species *H. pumilio* and *M. taihokui* are identical. He further advocated the exclusion of *H. cahirinus* from the genus *Haplorchis*. Katsuta in 1932 added *M. microrchis* and *M. yokogouri*, parasitic in dog, cat and experimentally in man. Tubangui in 1933 described an interesting parasite—*Haplorchis anguillarum*—from the intestine of a fish—*Anguilla mauritiana*.

As will be clear from the discussion at the end of the paper there is not much case for the retention of two separate genera—*Haplorchis* and *Monorchotrema*. *H. anguillarum* Tubangui cannot be retained under the genus *Haplorchis* on account of the presence of two testes in it.

**Haplorchis attenuatum n. sp.**

A very large number of these parasites was obtained from the intestine of *Macrones seenghala*—a common fresh-water fish in Northern India. The parasite occurs in association with two interesting trematodes of the genus *Bucephalus*, family Bucephalidae. The living worms are light yellow in colour and lack any marked power of contraction and expansion. The body is somewhat cylindrical and club-shaped, usually with a narrow neck which in its natural habitat lies buried in the wall of the intestine and a uniformly broad body. Rarely it is of uniform breadth throughout except towards the ends. The worms are small in size, measuring 1·3–2·2\* in length and 0·24–0·4 in maximum breadth across the region of the ovary and are thickly covered with small posteriorly directed spines of 0·007–0·008×0·0013 size. The spines gradually diminish both in number and size towards the hinder end.

The oral sucker is subterminal and broader than long, measuring 0·045–0·065×0·05–0·078 in size. Acetabulum is absent. The oral sucker opens into a long and narrow prepharynx of 0·19–0·32 length; the pharynx is small and oval, 0·05–0·052×0·037–0·04 in size, and lined internally with cuticle. The oesophagus, about  $\frac{1}{3}$  to  $\frac{1}{2}$  the length of prepharynx, i.e., 0·06–0·17 long, bifurcates into two long slender cæca which run laterally near the body wall and terminate blindly a little behind the testis.

The excretory bladder, as is characteristic of the family, is Y-shaped from the antero-lateral margins of which are given off two cornua. The bladder is 0·11–0·16 long and 0·035–0·06 broad at its anterior end. The excretory pore is terminal.

The testis, as is typical of the genus, is single, globular, rarely ovate, measuring 0·26–0·35×0·2–0·27 in size and situated in the median line in the first half of the post equatorial region. The vas deferens starts from the anterior border of testis and passes anteriorly along the left side to open into the vesicula seminalis. This latter lies obliquely to the left side extending from the level of the ventro-genital-sinus to the posterior end of the ovary and is deeply constricted into two oval chambers of varying sizes according to the amount of their contents; the anterior chamber measures 0·07–0·16×0·074–0·14 and the posterior 0·034–0·16×0·034–0·12 in size. The former chamber narrows anteriorly to form a small tubular prostate duct which continues forward as the ejaculatory duct of 0·04–0·08 length and meets the terminal part of the uterus to

\*All measurements are in mm.

form a short ductus hermaphroditicus or genital sinus which opens into the ventro-genital-sinus. The latter is an oval depression on the ventral body surface, close behind the intestinal bifurcation, slightly to the right side in level with the anterior margin of the vesicula seminalis. It is only

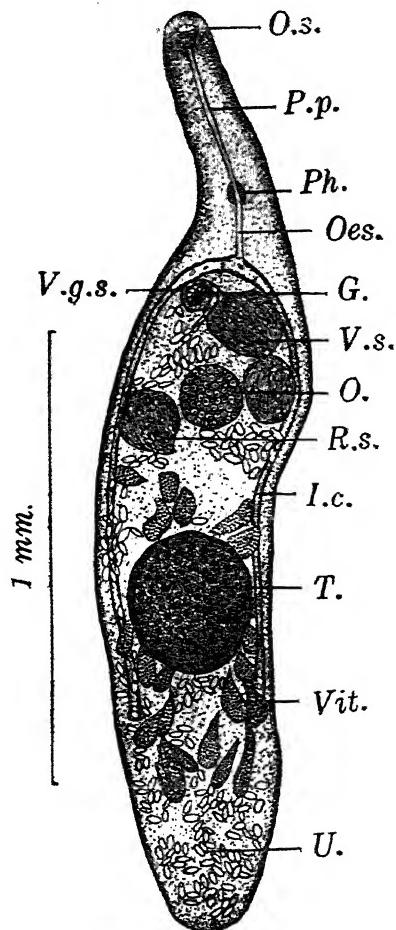


Fig 1.—Ventral View of *Haploorchis attenuatum*.

Pp. Prepharynx; G. Gonotyl; R. s. Receptaculum seminis; I. c. Intestinal cæca, T. Testis; O. Ovary; U. Uterus; O. s. Oral sucker; V.-g.-s. Ventro-genital-sinus; Oes. Oesophagus; V. s. Vesicula seminalis; Ph. Pharynx; Vit. Vitellaria.

slightly larger than the enclosed gonotyl and is drawn out into a small blunt process towards the anteriomedian corner, *i.e.*, towards the opening of the ductus hermaphroditicus. The gonotyl is almost a spherical, chitinous structure, 0'04—0'05 in diameter, slightly interrupted towards

the antero-median side and bearing a number of small, chitinous, radially arranged rodlets on its ventral surface.

The ovary is small, spherical, 0'1—0'14 in diameter, median, lying about half-way between intestinal bifurcation and testis. The seminal receptacle is globular, measuring 0'12—0'14 × 0'09—0'14 in size, depending on the amount of its contents and situated to the right in level with ovary, sometimes obliquely behind the latter. The Laurer's canal is given off from the junction of the receptaculum seminis and oviduct. The yolk reservoir and the shell gland complex lie in the space between the ovary and testis. The shell gland complex consists of an irregular mass of elongated acinous cells opening into the ootype.

The vitellaria lie in two lateral groups each composed of a number of elongated oval follicles varying from 0'07—0'17 × 0'03—0'05 in size. The vitelline glands of each side meet mesially in front of testis and extend from the receptaculum seminis to the hinder half of post-testicular region, overlapping the cæca and the testis. The two lateral vitelline ducts meet together in front of the testis to form a small yolk reservoir which opens into the oviduct just before the latter enters the ootype.

The uterus is well developed and occupies all the available space between the gonads and extends in irregularly arranged longitudinal coils from the ventro-genital-sinus to the hinder end. Eggs are numerous, operculate with a distinct 'shoulder' at the junction of the operculum and measure 0'032—0'035 × 0'015—0'017 in size.

In its relationship *H. attenuatum* n. sp. stands nearest to *H. cahirinus*. It resembles the latter species in the general topography of the organs, extent and arrangement of vitellaria and the host but differs from it in the shape of the body, smaller length of cæca which do not extend upto the hinder end, position of ovary, the size and extent of vesicula seminalis and in having, instead of five as in *H. cahirinus*, a fairly large number of radially arranged minute chitinous spines on the gonotyl, besides differences in the size of the various organs.

Host—*Macrones seenghala*.

Habitat—Intestine.

Locality—Allahabad (Rivers: Ganges and Jumna).

#### ***Haplorchis piscicola*, n. sp.**

The infection with these parasites, though never very heavy, is quite common in the winter months. The host is, however, found heavily in-

fected with a species of *Bucephalopsis*. The body is fusiform or oval with bluntly pointed ends; spinose, spines minute and backwardly directed measuring  $0\cdot01 \times 0\cdot0025$  in size. Adult specimens measure  $1\cdot32 - 2\cdot25$  in length and  $0\cdot53 - 0\cdot85$  in maximum breadth across the region of receptac-

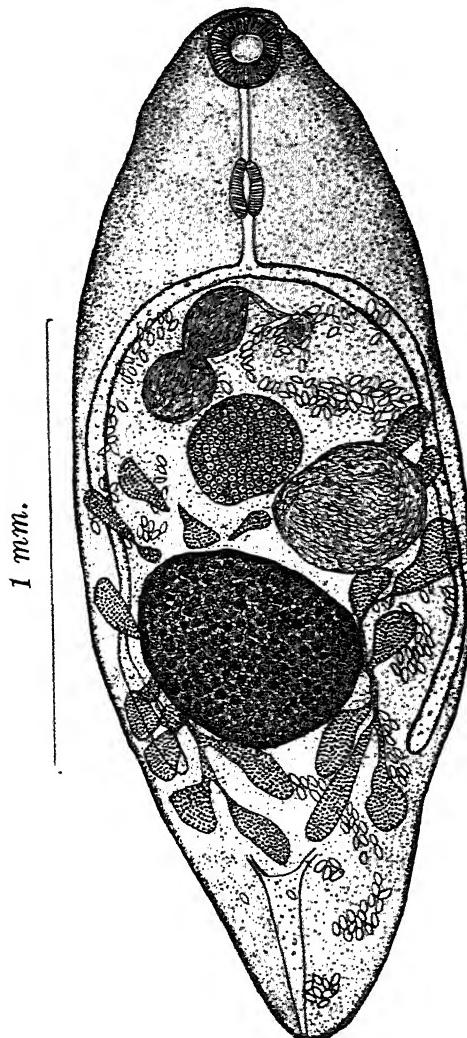


Fig. 2 - Ventral View of *H. piscicola*.

culum seminis. Oral sucker subterminal, powerful, spherical, of  $0\cdot1 - 0\cdot15$  diameter. Acetabulum absent. Prepharynx straight,  $0\cdot15 - 0\cdot16$  long; pharynx small, oval and muscular of  $0\cdot05 - 0\cdot09$  diameter; oesophagus  $0\cdot06 - 0\cdot14$  long; cæca lateral, moderately long and narrow ending a little beyond

testis. Ventro-genital-sinus enclosing the gonotyl lies slightly to the left, a little behind intestinal bifurcation, about half-way between the latter and ovary; gonotyl chitinous, nearly spherical,  $0.05-0.06$  in diameter, with a slight interruption at antero-median corner and bearing on its ventral surface a number of radially arranged small chitinous rodlets. Excretory bladder as in *H. attenuatum* but is larger in size.

Testis compact, massive, globular, rarely compressed ovate,  $0.22-0.45 \times 0.26-0.5$  in size, median, at times slightly to one side, close behind anterior half of body. Vesicula seminalis retort-shaped, extending obliquely on the right side from intestinal bifurcation to anterior half of ovary, bipartite, anterior part measuring  $0.15-0.17 \times 0.14$  and the posterior  $0.07-0.17 \times 0.1-0.15$  in size according to the amount of its contents; pars prostatica small and tubular; ductus ejaculatorius of  $0.06-0.1$  length joins the terminal part of the uterus near genital sinus. Ovary spherical,  $0.12-0.24$  in diameter, median, lying about middle of body, half-way between testis and genital sinus; receptaculum seminis thin-walled, massive, globular, of  $0.12-0.28$  size, situated to the left, obliquely behind ovary; Laurer's canal present; yolk reservoir and shell gland complex lie between ovary and testis. Vitellaria in two lateral groups, each composed of a large number of follicles of  $0.05-0.3 \times 0.03-0.14$  size, extending from level of ovary to the middle of testicular region and meet mesially in front of testis. Uterus occupies all available space between the gonads extending in longitudinal coils from intestinal bifurcation to hinder end; eggs operculate with a distinct "shoulder," measuring  $0.03-0.032 \times 0.017-0.02$  in size.

This species differs from *H. cahirinus* and *H. attenuatum* in the shape of the body, larger size of the various organs, smaller length of prepharynx, oesophagus and vesicula seminalis and the topography of the gonads.

Host—*Eutropiichthys vacha*.

Habitat—Intestine.

Locality—Allahabad (Rivers: Ganges and Jumna).

#### ***Haplorchis gangeticum*, n. sp.**

This species represents a fairly common parasite in the gut of Bachua, a common fish in the rivers of Northern India. The infection, however, is seldom heavy. Mature specimens are minute in size, measuring  $0.66-0.88$  in length and  $0.33-0.36$  in maximum breadth across the region of testis. Body oval with broadly rounded off ends, spinose,

spines minute and backwardly directed,  $0.005 \times 0.0025$  in size. Oral sucker subterminal, spherical, fairly large in size,  $0.09-0.125$  in diameter. Acetabulum absent. Prepharynx  $0.08-0.1$  long; pharynx oval,  $0.05-0.06 \times 0.04$  in size; œsophagus absent or rudimentary; cæca straight, narrow, lateral, ending at about middle of testis, rarely reaching its posterior end. Ventro-genital-sinus lies to the right a little behind the intestinal bifurcation, about half-way between the latter and ovary and enclosing a spherical, chitinous gonotyl of  $0.04-0.045$  diameter; the latter structure bears a number of minute chitinous rodlets on its ventral surface as in other species. The excretory bladder is as in *H. attenuatum*.

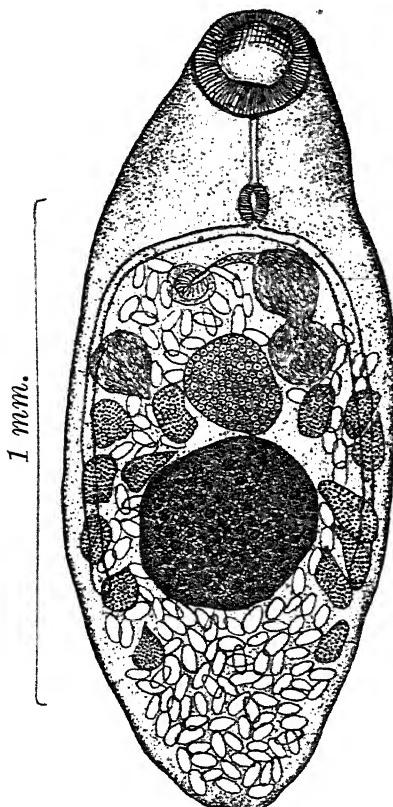


Fig. 3.—Ventral View of *H. gangeticum*.

Testis single, massive, spherical,  $0.1-0.19 \times 0.15-0.19$  in size, median, situated close behind middle of body. Vesicula seminalis bipartite, anterior part  $0.086-0.1$  and posterior  $0.07-0.09$  in size, extending obliquely on the left side from ventro-genital-sinus to middle of ovary; prostate duct short, ductus ejaculatorius  $0.025-0.05$  long and joins the uterus near

ventro-genital-sinus. Ovary small, spherical,  $0.07-0.1$  in diameter, median, situated close in front of or in contact with testis; receptaculum seminis globular,  $0.09-0.1$  in size, lying on the right side in level with anterior half of ovary; Laurer's canal present; Mehlis gland lies between ovary and testis. Vitellaria, as in other species, consist of large oval follicles,  $0.03-0.09 \times 0.01-0.05$  in size, situated laterally from vesicula seminalis to middle of post-testicular region. Uterus occupies all available space between intestinal bifurcation and hinder end of body; eggs operculate with a distinct "shoulder," measuring  $0.032-0.037 \times 0.013-0.017$  in size.

This species differs from all the species of the genus in the shape and size of body, absence of cesophagus, length of cæca, position of ovary and distribution of vitellaria which do not meet mesially in front of testis besides differences in the size of the various organs.

Host—*Pseudotropius athenoides*.

Habitat—Intestine.

Locality—Allahabad (Rivers: Ganges and Jumna).

### **Haplorchis silundii, n. sp.**

This is a very rare parasite of *Silundia gangetica*, the infection being never more than five percent. The fish is commonly infected with a large number of specimens of a species of *Bucephalopsis*. Body spindle-shaped, broad in the middle and tapering towards the ends, measuring  $1.6-2.0$  in length and  $0.36-0.4$  in maximum breadth across the level of ovary, spinose, spines minute backwardly directed, of  $0.01 \times 0.005$  size. Oral sucker sub-terminal, spherical,  $0.07-0.08$  in diameter; prepharynx very long,  $0.32-0.35$ , and slender; pharynx small and oval,  $0.042 \times 0.037$  in size; cesophagus fairly long,  $0.24$ ; cæca lateral, ending in level with hinder third of testis. Ventro-genital-sinus situated slightly to the left about the middle of body and enclosing a circular gonotyl studded with a number of minute chitinous rodlets and measuring  $0.05-0.06$  in diameter. The excretory bladder is as in other species. Acetabulum absent.

Testis massive, oval, of  $0.21-0.24 \times 0.18-0.21$  size, median, lying in posterior third of body; vesicula seminalis large, bipartite,  $0.17-0.21 \times 0.15-0.17$  in size depending upon the amount of its contents and lying obliquely to the left about the middle of body; prostate duct short; ductus ejaculatorius  $0.1-0.13$  long and joins the terminal part of uterus near ventro-genital-sinus. Ovary small, spherical,  $0.1-0.12$  in diameter, median, situated a little in front of testis; receptaculum seminis massive, of  $0.1-0.15$  size, globular, lying to the left of ovary. Laurer's

canal present. Yolk reservoir and Mehlis' gland lie between ovary and testis. Vitellaria poorly developed, consisting of a few large follicles, extending laterally from ovary to hinder end of testis and meeting mesially in front of the latter. Uterus extending from the genital pore

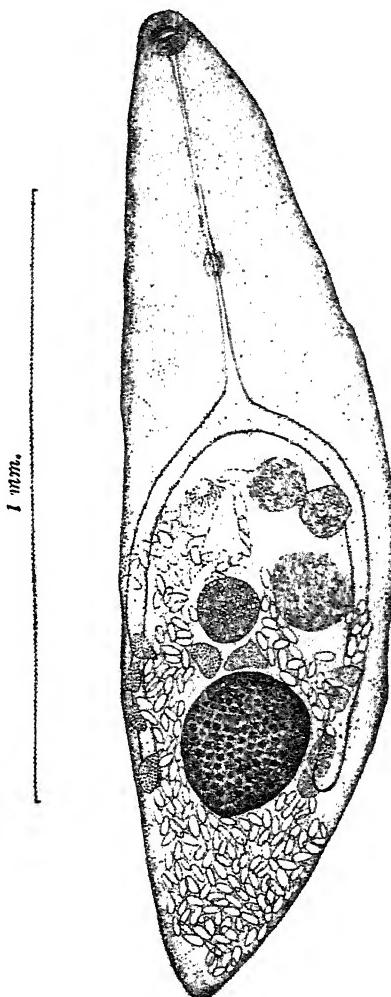


Fig. 4.—Ventral View of *H. silundii*.

to hinder end of body. Eggs operculate, with a distinct "shoulder," measuring  $0'032-0'035 \times 0'015-0'017$  in size.

This species differs from all the species of the genus in the markedly cauded position of the intestinal bifurcation and the reproductive organs,

length of prepharynx, œsophagus and cæca, restricted growth of vitellaria and shape and size of body.

**Remarks on the Genera *Haplorchis* Looss, 1899, and *Monorchotrema* Nishigori, 1924.**

Witenberg in 1930 emphasized the synonymy of the genera *Haplorchis* and *Monorchotrema* and pointed out the unmistakable identity between their type species, i.e., *H. pumilio* Looss, 1896, and *M. taihokui* Nishigori, 1924. He also removed *H. cahirinus* Looss, 1896, from the genus *Haplorchis* and even suggested its exclusion from the family, considering "its occurrence in a fish unnatural among the Heterophyidæ." The recent work of Mueller and van Cleave, 1932, Tubangui, 1933, and Manter, 1934, has clearly shown that the occurrence of members of the family Heterophyidæ in fish is as natural as in birds and mammals. Though the identity of the genera *Haplorchis* and *Monorchotrema*, as now constituted, cannot be denied on account of a close similarity in their entire anatomy and topography of organs, nevertheless, *H. pumilio* differs from *H. cahirinus* in the smaller length of prepharynx, cauded position of testis and vitellaria, presence of a rudimentary ventral sucker and host—characters sufficiently important to warrant the splitting up of the genus into two sub-genera: *Haplorchis* (*Monorchotrema*) and *Haplorchis* (*Haplorchis*). The former sub-genus contains *H. taichui*, *H. microrchis* and *H. yokogawai* with *H. pumilio* as its type and the latter sub-genus all the species described in this paper in addition to its type species *H. cahirinus*. *Haplorchis anguillarum* Tubangui, 1933, though closely related to *H. cahirinus*, cannot be retained under *Haplorchis* owing to the presence of two testes in it and a new genus *Tubanguia* is, therefore, proposed for its reception.

The diagnosis of the genus *Haplorchis* as given by Looss in 1899 needs to be modified in the light of the new forms discovered subsequently. The emended diagnosis is as follows:—

*Haplorchinæ*—Body small, elongated or oval with a narrow anterior and a slightly broader posterior end, cuticle spinose; oral sucker well developed; prepharynx moderately or exceptionally long; pharynx small, muscular; œsophagus moderately long or absent; cæca long, slender, lateral, ending in the region of or a little beyond testis or reaching hinder end of body. Acetabulum rudimentary or absent, when present embedded in ventro-genital-sinus. The latter median or slightly to one side close behind intestinal bifurcation. Gonotyl small, spherical, chitinous, embedded in ventro-genital-sinus and studded with either five big or a number of small

chitinous rodlets on its ventral surface. The excretory bladder  $\gamma$ -shaped, mainstem small, cornua reaching nearly up to anterior end. Testis single, massive, spherical or compressed ovate, situated in posterior half of body, usually median, rarely to one side; vesicula seminalis large, bipartite, prostate and ejaculatory ducts short, prostate glands poorly developed, ejaculatory duct joins the terminal part of uterus. Ovary spherical, pre-testicular, median or to one side and smaller than testis; Laurer's canal present; receptaculum seminis large, near ovary. Vitellaria consist of oval to elongated follicles extending laterally either up to or a little in front of posterior end and usually meeting mesially in front of testis. Uterus occupies nearly all the available space between genital pore and posterior end of body. Eggs numerous, rather large for the size of the parasite, with a distinct "shoulder" at the opercular end.

Host—Fish, birds and mammals, including man.

Habitat—Intestine.

Type—*H. pumilio* Looss, 1896.

I am much indebted to Dr. H. R. Mehra under whom this work was carried on for valuable help and advice. I am also thankful to Dr. D. R. Bhattacharya for the laboratory facilities in the Department. I am grateful to the Trustees of the Lady Tata Memorial Trust, Bombay, for the grant of a scholarship for investigations in Helminthology.

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CONTRIBUTIONS TO THE DIGENETIC TREMATODES  
OF THE MICROCHIROPTERA OF NORTHERN INDIA

Part 2.—Studies on the genus *Lecithodendrium* Looss

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Genus *Lecithodendrium* Looss 1896

Looss (1896) described six new species of distomes—*Distomum glandulosum*, *D. hirsutum*, *D. chefrenianum*, *D. pyramidum*, *D. obtusum* and *D. sphærula*,—and proposed for them with *D. ascidia* v. Beneden (1873), *D. ascidioides* v. Beneden (1873), and probably also *D. heteroporum* Dujardin (1845), a new generic name *Lecithodendrium*. After defining this genus in 1899 with *D. ascidia* as the type species, which he held identical with *D. ascidia* Rudolphi (1819) and placing it in his sub-family Brachycœliinæ, he gave an account of *L. lagena* Brandes (1888) and excluded *D. chefrenianum* from the list of the species assigned to this genus. Later, Braun (1900) pronounced *D. ascidioides* a synonym of *D. chilostomum* Mehlis (1831) and with a short description of *L. ascidia* (after v. Linstow, 1894) described a new species, *L. cordiforme*. The position of the vitellaria in *L. ascidia*, contrary to what v. Beneden had said, was stated to be posttesticular. Lühe (1901) and Looss (1902) advocated the removal of certain genera including *Lecithodendrium* without muscular cirrus-pouch from the Brachycœliinæ and placed them under a new sub-family Lecithodriinæ. In 1905 two more species of *Lecithodendrium* were added under the name *L. anticum* and *L. posticum* by Stafford. Looss (1907) gave an account of two new species, *L. granulosum* and *L. urna*. Odhner (1911) subdivided the genus *Lecithodendrium* into *Lecithodendrium* and *Paralecithodendrium*, grouping under the former sub-genus *lagena* (*D. ascidia* v. Beneden), *chilostomum*, *hirsutum*, *pyramidum*, *cordiforme*, *granulosum*, *urna* and *posticum*-species with more or less globular, post acetabular or at least partially para-acetabular ovary, while under the latter he placed *anticum*, *glandulosum*, *obtusum* and *sphærula*, species

with lobate or almost branched, pre-acetabular ovary. Faust (1919) described a new species (*Acanthatrium nycteridis*) and created for it and *L. sphaerula*,—both possessing a genital atrium lined with numerous spines and ant-acetabular testes in level with genital pore—a new genus, *Acanthatrium*. For all the species comprehended up to that time under *Lecithodendrium*, he restricted the generic name to only those which possess aspinose genital atrium, vitellaria in pharyngeal zone and the testes in plane with the acetabulum. Accordingly he included in this genus *ascidia*, *chefrenianum*, *chilostomum*, *cordiforme*, *obtusum*, *posticum*, *glandulosum*, and *pyramidum*. Travassos (1921) raised *Paralecithodendrium* to the rank of a genus. In 1926 Bhalerao described three new species, *L. longiforme*, *L. orospinosa* and *L. orimagnosum* from Burma and later (1926 a) added a fourth, *L. dinanatum*. Commenting on the classification adopted by Faust, he pointed out certain errors and was of the opinion that *L. ascidia* should be removed from *Lecithodendrium* and *urna* be placed under *Lecithodendrium*. From Philippine Islands Tubangui (1928) described *L. luxonicum* and the same year Travassos gave an account of another new species, *Puralecithodendrium liliputianum*. Mödlinger (1930) redescribed *L. ascidia*, *L. lagena*, *L. cordiforme* and *L. chilostomum* and confirmed the observations of v. Beneden about the position of the vitellaria in *L. ascidia*. A year later Dollfus, in a note, splitting up the genus *Lecithodendrium*, held *Lecithodendrium* and *Mesodenarium* Faust synonymous and included the species with pretesticular vitellaria under a new genus, *Prosthodendrium*, with *dinanatum* as its type species.

What has been said above is briefly an outline of the previous work on the genus, a perusal of which evidently shows the confusing difference of opinion on the grouping of the species into larger units. Odhner's sub-division of the genus is no longer acceptable in view of the fact that the character of the ovary—entire, lobed or branched—is not of sufficient importance and further its position anterior to the acetabulum in *Puralecithodendrium* has been recorded for a number of species included under *Lecithodendrium*. Faust's genus, *Acanthatrium*, based mainly on the spined nature of the genital atrium, should also be dropped, the other characters distinguishing it are present in a number of species of *Lecithodendrium*. Mödlinger's paper settles the controversy regarding the position of the vitellaria in v. Beneden's *ascidia* and *Prosthodendrium* Dollfus is, therefore, no longer valid. The genus *Lecithodendrium* will now have all the species which have hitherto been placed under the genera, *Paralecithodendrium*, *Acanthatrium* and *Prosthodendrium*. The main distinguishing character for the genus is the pretesticular vitellaria.

The present paper gives an account of three new species and a new variety of the genus which are met with in *Nycticejus kuhli*, *N. dormeri* and *Vesperugo abranus*, the common insectivorous bats available near Allahabad. I am deeply indebted to Dr. H. R. Mehra for his valuable help and guidance. Thanks are due to Dr. D. R. Bhattacharya for laboratory facilities in the Department.

### **Lecithodendrium loossii, n. sp.**

Host—*Vesperugo abranus*.

Position—Small intestine.

Locality—Mohamedpur (A village fifteen miles north of Allahabad).

The body is nearly ovoid and 0'77 in length and 0'51 in maximum breadth, attained just behind ovary in the uterine zone. The oral sucker, 0'06 in diameter, is subterminal and followed by a spherical pharynx of 0'03 diameter. The cesophagus is well developed. The two short club-shaped intestinal cæca extend up to the level of the genital pore. The acetabulum, 0'045 in diameter, is situated at 0'27 distance, i.e., at one third distance from the anterior end. The median genital pore lies somewhat nearer the acetabulum than the intestinal bifurcation. The excretory pore lies at the posterior tip of the body, the excretory bladder has the characteristic V-shaped appearance. A large number of unicellular glands are present in the body parenchyma anterior to the acetabulum.

The testes, nearly symmetrical, lie laterally with greater part of their length behind the acetabulum. The right testis measures 0'16 in length and 0'14 in breadth and the left one 0'12 in length and 0'17 in breadth. The pseudo cirrus-sac, somewhat pearshaped lies to the right side between the right testis and the acetabulum with a slight curvature towards the latter, and posteriorly in close contact with the anterior margin of the ovary. A much coiled vesicula seminalis fills its basal swollen half and anteriorly it is filled with a large number of well developed prostate gland cells.

The nearly spherical ovary, 0'1 in diameter, lies to the right a little distance behind the acetabulum. The shell gland-complex is situated somewhat median, inside and in level with the ovary. The Laurer's canal is present. The receptaculum seminis being absent, the initial part of the coiled uterus serves as a receptaculum seminis uterinum. The uterus completely fills the post-acetabular part of the body. The metraterm is almost straight and lies dorsal to the acetabulum. The vitellaria,

composed of 8-12 follicles each, lie laterally just in front of the testes extending anteriorly up to the middle of the oesophagus. Ripe eggs measure 0.025 in length and 0.012 in breadth.

*Remarks* :—In having the ovary behind the acetabulum, this species resembles *L. pyramidum*, *L. urna*, *L. posticum*, *L. dinanatum*, and *L. liliiputianum*. But it differs from them, as well as from all the species of genus, in the position and extent of its pseudocirrus-sac which lies to the side of the acetabulum instead of in front of it. The position of the ovary in relation to the acetabulum is also a distinctive feature of this species.

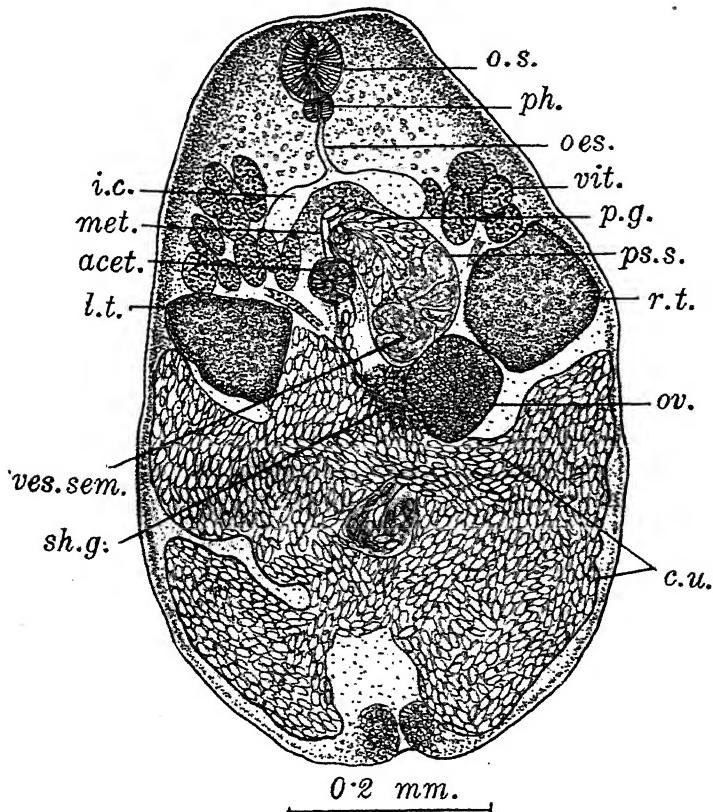


Fig. 1. Dorsal view of a mounted specimen of *Lecithodendrium loosii*, n. sp.

acet., acetabulum; c. u., uterine coils; g. o., genital opening; i. c., intestinal cæcum; l. t., left testis; met., metraterm; oes., oesophagus; o.s., oral sucker; ov., ovary; p. g., prostate gland cells; ph., pharynx; ps. s., pseudocirrus-sac; r. s., receptaculum siminis; r. t., right testis; sh. g., shellgland-complex; v. sem., vesicula seminalis; vit., vitellaria; y. d., yolk duct.

**Lecithodendrium mehrae, n. sp.**

Host—*Nycticephalus dormeri*.

Position—Small intestine.

Locality—Mohamedpur (A village fifteen miles north of Allahabad).

These distomes, spheroid to oval in shape, are firmly attached to the intestinal wall of the host. They are not capable of active movements and measure 0·85—1·02 in length and 0·65 in maximum breadth which is attained at the level of the genital pore. The very powerful oral sucker, with transversely placed mouth opening, is broader than long, measuring 0·25—0·28 × 0·32—0·37 in size. The pre-pharynx is present. The globular pharynx, 0·075 in diameter, is followed by a short oesophagus. The wide intestinal cæca lie more or less in a straight line transverse to the body length. The circular acetabulum is extremely small in proportion to the oral sucker, measuring 0·087—0·097 in diameter, and is situated at three fourths of the body length, i.e., 0·65—0·73 behind the anterior end. The median genital pore lies just in front of the acetabulum. The excretory pore, at the posterior lip of the body, leads into a V-shaped bladder with short median stem, which is surrounded by a large number of cells. The cornua of the bladder extend anteriorly to the neighbourhood of the testes.

The testes, laterally situated and globular in outline, lie symmetrically immediately behind the intestinal cæca and measure 0·24 in diameter. The pseudo cirrus-sac, median in position, lies just in front of the acetabulum. Its swollen basal part, which lies between and about the hinder margins of the testes, contains a large, coiled vesicula seminalis.

The ovary, 0·14 × 0·17 in size, has its greater part to the right side of the median line. It overlaps anteriorly the posterior margins of the right cæcum touching externally the inner side of the right testis. The shell-gland-complex and a well-developed receptaculum seminis lie to the left side of the ovary nearer its hinder margin between it and the left testis. The uterus, composed of descending and ascending coils, fills the post-testicular and intertesticular region of the body. The ascending coils, before they open to the exterior at the genital pore, lie ventral to the testes and the ovary, extending up to the intestinal cæca. The vitellaria, of 8—10 follicles on each side, lie lateral to the posterior half of the oral sucker and the pharynx slightly overlapping the cæca which separate them from the testes. The ripe eggs measure 0·022 by 0·012 in size.

*Remarks* :—This species differs from all the species hitherto included under the genus *Lecithodendrium* in the enormous size of its oral sucker, the great difference in the ratio between it and the acetabulum, the

position of the acetabulum near the hinder end of the body and the uterus extending far in front up to the posterior margin of the cæca. The position of the pseudocirrus-sac in relation to the testes is also a distinctive feature of this species.

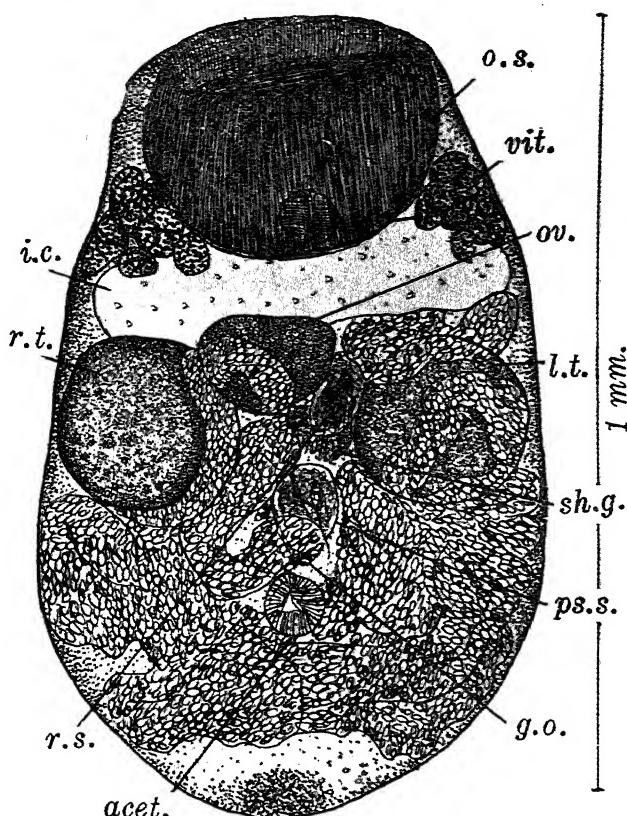


Fig. 2. Ventral view of a mounted specimen of *L. mehraei*, n. sp.

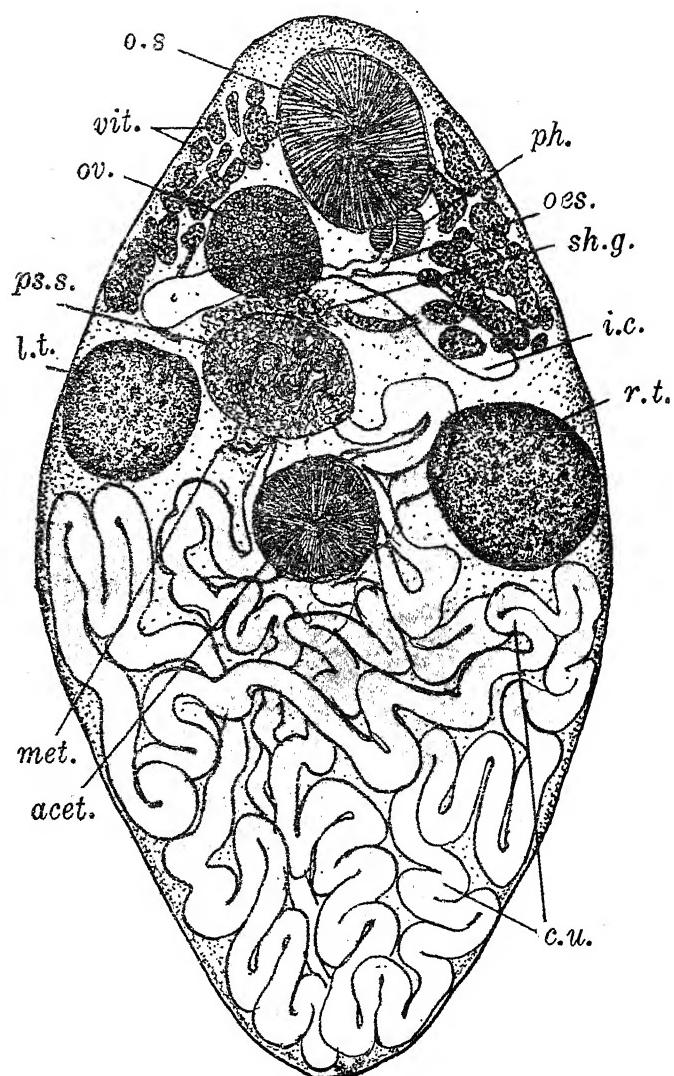
### ***Lecithodendrium bhaleraoi*, n. sp.**

Host—*Nycticejus kuhli*.

Position—Small intestine.

Locality—Allahabad.

This distome, nearly oval in shape, is 2.69 in length and 1.5 in maximum breadth, across the ventral sucker. The subterminal oral sucker is longer than broad and measures 0.47×0.37 in size. The pharynx is 0.1 in length and 0.14 in breadth. The oesophagus is short, bifurcating into club-shaped intestinal cæca, which run obliquely



1 mm.

Fig. 3. Dorsal view of a mounted specimen of *L. bhaleraoi*, n. sp.

outwards terminating slightly in front of the testes. The acetabulum, 0'32 in diameter, lies slightly in front of the middle of the body. The genital pore is situated to left side in front of the acetabulum. The excretory system presents a V-shaped appearance.

The testes are lateral and slightly in front of one another. The left testis,  $0'37 \times 0'34$  in size, lies in level with the pseudocirrus-sac while the right one, 0'42 in diameter, is in level with the acetabulum. The pseudocirrus-sac is situated just in front of the acetabulum.

The spherical ovary, with entire margins, lies to the left much in front of the testes and anterior to the pseudocirrus-sac overlapping the left cæcum and measuring  $0'32 \times 0'34$  in size. The shellgland-complex lies between the ovary and the pseudocirrus-sac. The receptaculum seminis is absent and the initial part of the uterus forms a receptaculum seminis uterinum. The Laurer's canal is present. The uterus is much coiled and occupies the entire post-acetabular space. A small metraterm is present. The vitellaria, composed of 20–30 follicles each, are laterally situated extending from near the blind ends of intestinal cæca to the anterior limits of the oral sucker. The ripe eggs measure 0'032 by 0'015 in size.

*Remarks.*—This form approximates the Burmese species, *L. orospinosa*, Bhalerao, more than any other species of the genus *Lecithodendrium* but it can be distinguished from the latter on account of the absence of spines on the oral sucker, smaller size of the suckers in relation to body length, position of the testes and ovary, absence of the receptaculum seminis and the complete separation of the vitellaria from one another (in *L. orospinosa* the vitellaria are united with one another in the median line). Bhalerao has not indicated the presence of a metraterm in his species.

#### ***Lecithodendrium longiforme*, var. *allahabadi*, n. var.**

Host—*Nycticejus kuhli*.

Position—Small intestine.

Locality—Allahabad.

These distomes, oval to pyriform in shape, are 1'9—3 in length and 0'8 in maximum breadth, which lie in the acetabular zone. The subterminal oral sucker, with longitudinal mouth opening, is longer than broad and measures  $0'22-0'44 \times 0'29-0'37$  in size. The unicellular gland cells are present in the parenchyma around the first half of the oral sucker. The prepharynx is short. The pharynx is  $0'09-0'1 \times 0'1-0'13$  in size; and the

œsophagus about twice as long as the pharynx. The intestinal cæca extend obliquely up to the testes. The acetabulum, smaller than the oral sucker, and 0'22—0'3 in diameter, is situated at about the middle of the body length. The genital pore lies to the left of the median line in front of the acetabulum. The excretory pore lies at a short distance in front of the posterior tip and leads into a spherical chamber which is surrounded by a large number of cells with prominent nuclei. The cavity of this chamber is divided by a number of septa arising from its inner walls. This globular chamber passes anteriorly into a short median stem which divides into two long cornua of the bladder extending up to the posterior limits of the testes.

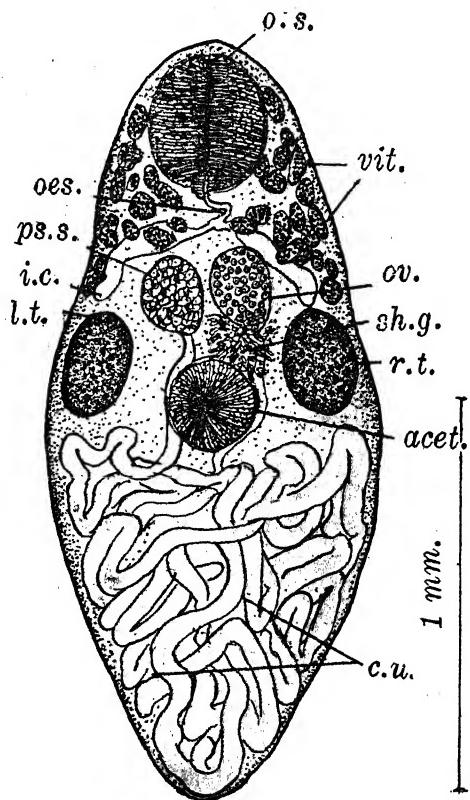


Fig. 4. Dorsal view of a mounted specimen of *L. longiforme* var. *allahabadi*, n. var.

The testes, globular to oval, lie symmetrically in the acetabular zone and a little in front of it. The right testis measures 0'27—0'46 × 0'2—0'44 in size and the left is 0'27 × 0'17 in size. The pseudocirrus-sac lies slightly

to the left between the acetabulum and intestinal bifurcation nearer the left cæcum and measures  $0'19-0'34 \times 0'19-0'37$  in size.

The ovary, oval in shape and  $0'22-0'34 \times 0'17-0'37$  in size, lies in level with and to the right side of the pseudocirrus-sac. The oviduct arises from its posterior end and passes into the ootype which continues into the Laurer's canal. The yolk-reservoir lies ventral to the ootype. The shellgland cells lie between the ovary and anterior margins of the acetabulum. The receptaculum seminis is absent. The first few coils of the uterus serve as receptaculum seminis uterum. The uterus, after its origin from the ootype, passes behind to form the numerous uterine coils, which fill the entire post-acetabular space. The somewhat straight metraterm lies to the left of the acetabulum. The vitellaria, of 20—30 follicles on each side, extend from the hinder ends of intestinal cæca to near the middle of the oral sucker, lying laterally to the latter, pharynx, oesophagus and intestinal cæca. The ripe eggs measure  $0'032-0'035$  in length and  $0'015-0'017$  in breadth.

*Remarks* :—These specimens resemble in all essential features *Lecithodendrium longiforme*, Bhalerao, but they differ from it in the presence of unicellular glands and absence of the receptaculum seminis. Moreover, Bhalerao has not mentioned the presence of a metraterm and the spherical chamber of the excretory bladder in his species. I consider my specimens to belong to a new variety for which the name *Lecithodendrium longiforme*, var. *allahabadi* is suggested.

All measurements in Millimetres.

#### Key to the species of the genus *Lecithodendrium*

Ovary in front of acetabulum	...	...	A
Ovary lateral to acetabulum	...	...	B
Ovary behind acetabulum	...	...	C
A. Ovary entire margined	...	...	1
Ovary lobed	...	...	2.
1. Testes symmetrical in acetabular plane	...	I	
Testes symmetrical, in front of acetabulum, in level with or ahead of genital pore.		II	
Testes asymmetrical, one in front of another.	<i>L. bhaleraoi</i> , n. sp.		
I. Vitellaria lateral to oesophagus and intestinal cæca.		<i>L. ascidia</i> .	

- Vitellaria lateral to posterior half of oral sucker, pharynx, oesophagus, and intestinal cæca ... ... ... *L. longiforme*.
- II. Oral sucker larger than acetabulum ... (a)
- Oral sucker slightly smaller than acetabulum, ovary to right and well in front of acetabulum ... ... ... *L. anticum*.
- (a) Oral sucker covered with spines; vitellaria meeting centrally ... ... ... *L. orospinosa*.
- Oral sucker not covered with spines ... (b)
- (b) Vitellaria from in front of testes to near posterior limits of oral sucker ... (c)
- Vitellaria separated from testes by intestinal cæca ... ... ... *L. mehrai*, n. sp.
- (c) Oesophagus absent, genital pore closer to pharynx. *L. luxomicum*.
- Oesophagus present ... ... ... *L. chilostomum*.
2. Genital atrium devoid of spines ... (a)
- Genital atrium armed with spines ... *L. sphærula*.  
(Syn. *Paralecithodendrium sphærula* and *Acan. sphærula*).
- (a) Genital pore median ... ... ... (b)
- Genital pore to right ... ... ... *L. glandulosum*.  
(Syn. *Paralecithodendrium glandulosum*.)
- (b) Ovary overlaps testes partially; testes in the same plane as acetabulum ... *L. ovimagnosum*.
- Ovary to right, in some cases median; posterior border of testes nearly in line with centre of acetabulum ... ... *L. obtusum*.  
(Syn. *Paralecithodendrium obtusum*)
- B. Genital atrium aspinose ... ... ... *L. cordiforme*.

Genital atrium spinose	...	...	<i>L. nycteridis.</i>
			(Syn. <i>Acanthatrium nycteridis</i> ).
C. Pseudocirrus-sac between acetabulum and intestinal bifurcation	...	...	(a)
Pseudocirrus-sac on the side of acetabulum	<i>L. loossi</i> , n. sp.		
(a) Suckers moderately developed	...	...	(c)
(b) Suckers relatively much larger in proportion to body size; body 0'28—0'29 in length and 0'17—0'20 in breadth, oral sucker 0'08—0'09 and acetabulum 0'11 in diameter.	<i>L. liliputianum.</i>		
	(Syn. <i>Paralecithodendrium liliputianum</i> .)		
(c) Testes on either side of acetabulum	...	...	(d)
Testes with only anterior margins at level of acetabulum	...	...	<i>L. urna.</i>
			(Syn. <i>Mesodendrium urna</i> .)
Testes little anterior to acetabulum; ovary contiguous to acetabulum	...	...	<i>L. pyramidum.</i>
(d) Ovary slightly overlapping acetabulum	...	...	<i>L. dinatum.</i>
			(Syn. <i>Prosthodendrium dinatum</i> .)
Ovary in angle between acetabulum and right testis.	...	...	<i>L. posticum.</i>

#### SUMMARY

A brief historical account of the genus *Lecithodendrium* Looss is given. The genera *Paralecithodendrium* Odhner, *Acanthatrium* Faust and *Prosthodendrium* Dollfus have been dropped and held synonymous with *Lecithodendrium*.

Three new species of *Lecithodendrium* and a new variety of *L. longiforme* Bhalerao are described. These, collected from three species of common insectivorous bats available near Allahabad, are:

*Lecithodendrium loossii*, n. sp.

*L. mehrai*, n. sp.

*L. bhaleraoi*, n. sp.

*L. longiforme* var. *allaha'adi*, n. var.

A key to the species of *Lecithodendrium* is also appended.

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NEW TREMATODES OF THE FAMILY LECITHODENDRIIDÆ  
ODHNER, 1911 WITH A DISCUSSION ON THE CLASSI-  
FICATION OF THE FAMILY.

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**Introduction**

In this paper are described a new genus *Exotidendrium* from the Indian gharial-*Gavialis gangeticus* and two new species of the genus *Eumegacetes* Looss, 1900, from an Ashy Swallow-Shrike at Allahabad, and further, in a discussion on the classification of the family Lecithodendriidae are expressed my views about the relationships of the genera which form the basis of the division of this family into subfamilies.

Travassos (1922) excluded the genus *Eumegacetes* from the family Lecithodendriidae to which Odhner (1911) had assigned it, and created a new family Eumegacetidae for it. Poche (1925) finds no justification for the creation of this family, but to this Travassos (1928) does not agree, maintaining the Eumegacetidae, of which he gives the diagnosis. I drop the latter family and reduce it to the rank of a subfamily in the family Lecithodendriidae. The number of families included in the Digenea is so large that a tendency to multiplication of unnecessary families should be deprecated.

According to the revised classification given here the family Lecithodendriidæ includes the subfamilies Lecithodendriinæ Looss, 1902, Pleurogenetinæ Looss, 1899, Anchitreminæ n. subf., Eumegacetinæ n. subf., Phaneropsolinæ n. subf., and Exotidendruinæ n. subf. The genera established in this paper are *Exotidendrium* with the type species *Exotidendrium gharialii*, n.g., n.sp., *Lecithoporus* with the type species *Lecithoporus (Pycnoporus) inversus* Looss, 1907 and *Pleuropsolus* with the type species *Pleuropsolus (Phaneropsolus) insolens* (Bhalerao, 1926.)

***Exotidendrium gharialii*, nov. gen., nov. spec.**

The trematodes of this genus were obtained in 1932 and 1933 in large numbers from the rectum near the cloaca of *Gavialis gangeticus* at

Allahabad. Nearly 25 per cent hosts were found infected with this parasite. The distome is very minute, measuring 1—1.35\* in length and 0.34—0.36 in maximum breadth which lies at about the middle of the body length, a little behind the ventral sucker. The body is elongated with the anterior neck like narrow part capable of great extension and contraction, tapering to a blunt point at the anterior end and narrow and slightly rounded at the posterior end. The shape varies considerably on account of the great capacity of elongation and retraction of the anterior part, so that in some fully extended specimens the anterior part is very long and narrow, arising from a short stumpy posterior body. In much contracted specimens, however, the whole body is shortened, presenting a variety of curious shapes. The cuticle is armed with small pointed spines, which become sparse behind the ovary and are altogether absent near the hinder end. The spines are longer and much more numerous in front of the ventral sucker. The cutaneous gland cells are present embedded in the parenchyma for a great part of the body length. The suckers are feebly muscular. The oral sucker is subterminal, measuring 0.03—0.04 in diameter. The ventral sucker is larger, 0.05—0.068 in diameter, and lies a little in front of the middle of the body. The ratio between the size of the two suckers is about 2:3. The prepharynx is fairly long, measuring 0.034—0.04 in length. The pharynx is elongated oval in shape, 0.037—0.04 in length and 0.024—0.027 in maximum breadth. The oesophagus is long, but its length varies due to the state of extension of the anterior part of the distome. The intestinal cæca are extremely short and moderately wide or somewhat saccular, terminating at about the level of the anterior or posterior margin of the ventral sucker. At the point of bifurcation they diverge from each other at about a right angle; but in contracted specimens the angle is larger approaching 180° as in some species of the genus *Lecithodendrium*. The salivary gland cells are well developed and form a more or less dense covering around the gut from the pharynx to the ends of the cæca.

The excretory opening is subterminal, situated dorsally in front of the hinder end, and is surrounded by a group of large parenchymatous cells which function as a sphincter. The excretory bladder is V-shaped; the cornua could not be traced anteriorly on account of innumerable ova covering this region.

The genital opening lies median, immediately behind the intestinal bifurcation, at a little distance in front of the ventral sucker. The testes

\* All measurements are given in mm.

lie opposite to one another nearly at the same level, in front of the ovary and immediately behind the ventral sucker, at about the middle of the body length; the right testis is usually shifted a little more forwards, extending

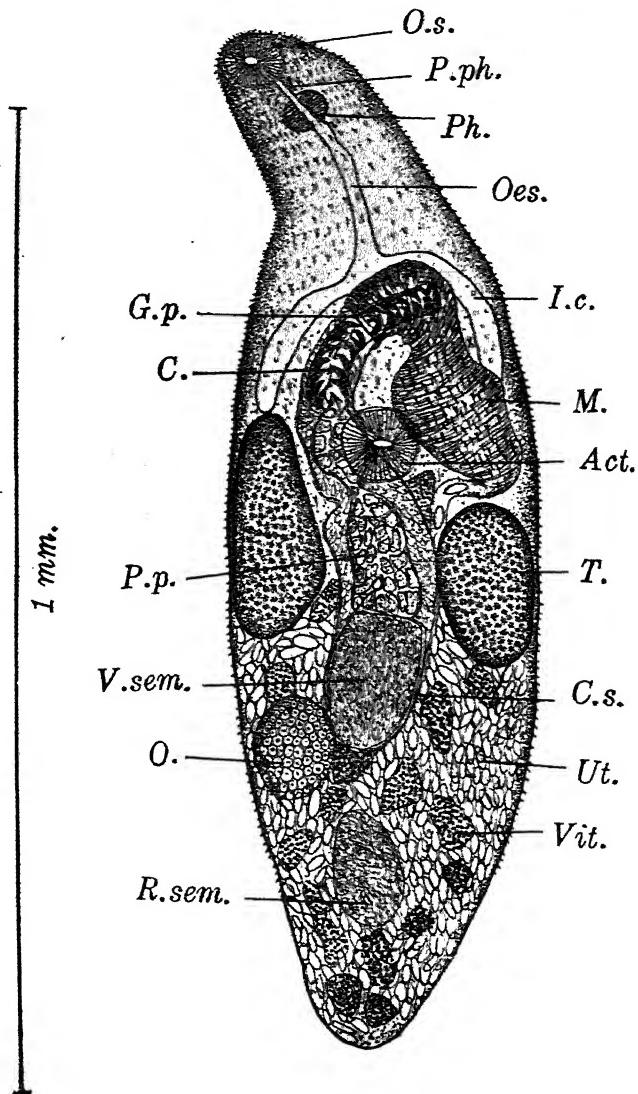


Fig. 1.—Ventral View of *Exotidendrium gharialii*, n.g., n.sp.

Act: Acetabulum; C: Cirrus; Cs: Cirrus sac; G.p.: Genital pore; I.c.: Intestinal cæcum; M: Metraterm; O: Ovary; O.s: Oral sucker; Oes: Oesophagus; P.p: Pars prostatica; Ph: Pharynx; P.ph: Prepharynx; R.sem: Receptaculum seminis; S.gl.m: Shell gland mass; T: Testis; Ut: Uterus; V.sem: Vesicula seminalis; Vit: Vitellaria;

up to or a little beyond the anterior margin of the ventral sucker. They are longer than broad and somewhat oval in shape with entire margins, measuring 0'149—0'2 in length and 0'085—0'2 in maximum breadth. The cirrus sac is very large, elongated, somewhat sickle or S-shaped, extending far behind the ventral sucker to middle of the ovary or sometimes even behind it to a little in front of the hinder end. It lies median or slightly to the right side with its long axis parallel to the length of the body and narrow terminal part curved in a crescent-shaped manner towards the ventral sucker, measuring 0'47—0'54 in length and 0'1 in maximum breadth at a little distance in front of its base. In contracted specimens, however, the cirrus sac is sometimes more deeply curved like a half moon with its basal end to the extreme right or left side of the body. The vesicula seminalis, 0'1—0'136 long and 0'07—0'098 broad, is straight and ovoid with a wide anterior end, and occupies basal part of the cirrus sac. The pars prostatica of 0'187 length and 0'05 maximum breadth, is long and constricted a little beyond the middle so as to consist of a large proximal and small distal parts. The prostate gland cells occupy the entire space between the pars prostatica and walls of the cirrus sac. The cirrus is long, cylindrical and closely beset with large rose thorn-shaped spines of 0'0136—0'017 length and 0'0068 maximum breadth at the base. It is sharply marked off from the pars prostatica; and when protruded it is crescent-shaped, narrow at the base and broad at the free end, measuring 0'14—0'163 in length and 0'027—0'068 in maximum breadth. The ovary, somewhat ovoid with entire margins and 0'088—0'11 in length and 0'054—0'075 in maximum breadth, lies in the median line or to the right side, at about three quarter body length from the anterior end, a little behind the right testis near basal end of the cirrus sac. The receptaculum seminis, more or less ovoid in shape, 0'1—0'136 in length and 0'068—0'08 in maximum breadth, lies behind the ovary a little in front of the hinder end. The Laurer's canal has not been observed. The uterus is much coiled, occupying nearly the whole posterior half of the body, behind and between the gonads and cirrus sac. It forms too crowded a mass for individual coils to be observed, and passes upwards between the cirrus sac and the left testis to terminate in the large, spacious and highly muscular metraterm which is armed internally with scattered chitinous spines of 0'0068—0'01 length and 0'0034 maximum breadth at the base. The metraterm is situated to the left, opposite the terminal part of the cirrus sac, occupying the entire space between the ventral sucker and left body wall. It is saccular with its long axis parallel to the length of the body and its distal end bent towards the median line to open at the genital pore, measuring

0·255—0·34 in length and 0·126 in greatest breadth at about the middle of its length. The ova are numerous, fairly thick shelled, yellow brown in colour and operculated with a fine filament at the non-operculated end, measuring 0·017—0·0221 in length and 0·01—0·0112 in greatest breadth. The vitellaria consist of a relatively small number of large conical or pear-shaped follicles, which are not restricted to the lateral regions, but on the other hand, are scattered across the entire body from the ventral sucker to the hinder end. The transverse vitelline ducts are small; the yolk reservoir lies a little to the right close behind the ovary in front of the receptaculum seminis.

Host—*Garialis gangeticus*.

Habitat—rectum.

Locality—Allahabad, India.

#### **Diagnosis and Systematic Position of the genus *Exotidendrium*. n.g.**

Generic diagnosis:—

Lecithodendriidæ: Body minute, elongated, covered with spines; suckers feebly muscular; ventral sucker larger, a little in front of middle of body; ratio in size of suckers 2:3. Prepharynx and pharynx present; oesophagus long; intestinal cæca extremely short and somewhat saccular, not extending behind ventral sucker; gland cells present around entire gut. Excretory pore subterminal, dorsal; excretory bladder V-shaped. Genital opening median, immediately behind intestinal bifurcation, a little in front of ventral sucker. Testes nearly parallel, preovarian, immediately behind ventral sucker at about middle of body length. Cirrus sac very large, extending far behind ventral sucker to a little distance in front of hinder end, somewhat sickle or S-shaped. Vesicula seminalis straight, ovoid, inside cirrus sac; pars prostatica long; prostate gland cells well developed; cirrus long, cylindrical, closely beset with large rose thorn-shaped spines. Ovary entire, median or dextral near basal end of cirrus sac. Receptaculum seminis large, behind ovary, a little in front of hinder end. Vitellaria of follicles scattered across entire body from ventral sucker to hinder end. Uterus much coiled in posterior half; metraterm large, saccular, muscular, armed internally with scattered spines. Ova numerous, yellow brown, operculated with a fine filament at nonoperculated end, 0·017—0·0221 in length and 0·01—0·0112 in greatest breadth.

Host: *Garialis gangeticus*. Type species: *E. gharialii*.

The genus *Exotidendrium* belongs to the family Lecithodendriidæ Odhner on account of the V-shaped excretory bladder, small size and saccular form of the intestinal cæca, general topography of the genital

organs and size of the ova. It is distinguished from all the genera of the family in the great size of the cirrus sac and its position with regard to the testes and ovary, straight vesicula seminalis, long pars prostatica and strongly developed cirrus armed with large rose-thorn-shaped spines. It is also remarkable in having the ovary and the receptaculum seminis near the hinder end and a large saccular metraterm armed with scattered spines. The presence of a polar filament in the ovum and the habitat in a crocodilian host are also distinctive features of this genus.

It stands closer to the subfamily Lecithodendriinæ on account of the median preacetabular position of the genital opening, while in the possession of a large cirrus sac it resembles the subfamily Pleurogenetinæ; but as it differs in certain important features from the members of both these subfamilies, it is considered desirable to create a new subfamily for it

#### **Discussion on the Classification of the Family Lecithodendriidae Odhner.**

Though much work has been done on the Lecithodendriidæ, the authors do not agree about the systematic position of a number of genera and the classification of the family is far from satisfactory. Looss created the two subfamilies Lecithodendriinæ (1902) and Pleurogenetinæ (1899) which Odhner later (1911) included in his family Lecithodendriidæ. Lühe (1909) recognised the subfamilies Pleurogenetinæ Looss and Brachycoeliinæ Looss, the latter being equivalent to the Lecithodendriinæ Looss plus the genus *Brachycoelium*. Odhner in 1911 in his account of the Lecithodendriidæ removed all the genera from the Brachycoeliinæ except *Brachycoelium* to the Lecithodendriinæ, in which he also included the isolated genera *Anchitrema* Lss and *Eumegacetes* Lss. Travassos (1921 and 1928) also divides this family into two subfamilies, Lecithodendriinæ and Pleurogenetinæ; in the former he included the genera *Lecithodendrium*, *Paralecithodendrium*, *Acanthatrium* and *Castroia*, in the latter the genera *Pleurogenes*, *Pleurogenoides*, *Limatulum*, *Loxogenes*, *Parabascus*, *Prosotocus*, *Brandesia*, *Phaneropsolus*, and *Mosesia*. Travassos (1922 and 1929) created the family Eumegacetidæ for the genus *Eumegacetes*, which Poche (1925) following Odhner, assigned to the Lecithodendriidæ. Mehra and Negi (1928) accepted Odhner's views about the relationship of the subfamilies Lecithodendriinæ and Pleurogenetinæ and divided the genus *Pleurogenes* into two subgenera, *Pleurogenes* and *Telogonella*, which Travassos (1930) considered synonymous to the genera *Pleurogenoides* Travassos and *Pleurogenes* Looss respectively. Fuhrmann (1928) includes under Lecithodendriinæ, *Lecithodendrium*,

*Pycnoporus Phaneropsolus*, *Parabascus*, *Mesodendrium*, *Acanthatrium*, *Limatulum* and *Castroia* and under the Pleurogenetinae *Pleurogenes*, *Loxogenes*, *Prosotocus*, *Mosesia*, *Postorchigenes*, *Brandesia*, *Pleurogenoides*, *Ganeo*, *Eumegacetes* and *Anchitrema*. Stiles and Nolan (1931) in their useful key adopt mainly Travasso's classification with certain amendments in conformity with Looss's and Odhner's ideas about the diagnosis of the genera and subfamilies. Srivastava (1934) has referred to the untenability of the genus *Loxogenes* and the family Eumegacetidae and also drops the genus *Pleurogenoides*, preferring the division of the genus *Pleurogenes* into two subgenera created by Mehra and Negi, on account of a number of intermediate species which stand between them. His tentative classification of the genera *Phaneropsolus*, *Limatulum*, *Mosesia*, *Anchitrema* and *Eumegacetes* in the Lecithodendriinae is not based on any sure ground and obviously needs revision.

There is no doubt that the family Eumegacetidae Travassos is untenable and must be dropped. Odhner has established the relationships of the genus *Eumegacetes* with *Phaneropsolus* and other Lecithodendriinae. Here is another instance of a family having been created mainly on the basis of the excretory bladder; the case of the Reniferidae we have already discussed before (1931). The so-called Y-shaped excretory bladder of *Eumegacetes* having a very short stem and long cornua with lateral branches approaches a V-shaped rather than a Y-shaped condition. Moreover, in *Pleurogenes bicolor* Krull (1933) (syn. *Loxogenes bicolor*) the excretory bladder is distinctly Y-shaped with a long main stem and short cornua, a condition which is very exceptional for the family and its typical genus *Pleurogenes*. It, therefore, follows that too much importance should not be attached to the shape of the bladder in such systematic considerations. As regards the presence of lateral branches in the cornua we have already remarked in connection with the Reniferidae that they have arisen independently in various genera such as *Styphlodora*, *Styphlotrema*, *Pachypsolus*, *Knodiotrema*, *Renifer*, *Ochetosoma*, etc., as a specialisation and should not be considered to be of family or subfamily importance. In the position of the genital opening closely behind the pharynx, position of the testes, presence of the cirrus sac, tubular pars prostatica, short cirrus and the habitat in birds, *Eumegacetes* resembles the genus *Phaneropsolus*. But it differs sufficiently from all the Lecithodendriidae in the general topography of the genital organs, position of the genital opening, condition of the cirrus sac and the excretory bladder, great length of the cæca and vitellaria and its habitat in the rectum and cloaca of birds so as to necessitate the creation of a separate subfamily for it.

The Pleurogenetinæ is a well defined subfamily, consisting of genera which are closely related to one another. It appears to us that this subfamily represents the primitive condition of the family Lecithodendriidæ. The presence of a well developed cirrus sac, great variability in the length of the intestinal cæca and vitellaria and primary habitat in the amphibian and reptilian hosts point to that direction. The genus *Ganeo* in which the genital opening is present to the left side as in the typical Pleurogenetine has lost the true cirrus sac. The Lecithodendriinæ, which are parasitic in bats, have been obviously evolved from some primitive Pleurogenetine in which the genital opening was median or slightly to the left side a little in front of the ventral sucker as in *Exotidendrium* and *Phaneropsolus insolens* Bhalerao, with the loss of a true cirrus sac. The genital opening in the Lecithodendriinæ, no doubt, has retained its primitive median or submedian position in front of the ventral sucker, as in the typical Lepodermatidæ, such as *Lepoderma*, *Tremiorchis*, *Astiotarema* and *Styphlodora* which, as will be shown subsequently, are closely related to the Lecithodendriidæ. *Phaneropsolus insolens* Bhalerao (1926) apparently does not belong to the genus *Phaneropsolus*. The position of the genital pore to the left side of the median line close in front of the ventral sucker and much behind the pharynx is sufficient to warrant its removal from this genus. Moreover, the cirrus sac is much shorter, and does not extend anterior to the intestinal bifurcation, but on the other hand, overlaps the ventral sucker and lies partly anterior to it. Bhalerao has himself pointed out that his species differs in these features from all the other species of *Phaneropsolus* except *P. microon* Rud. (1819). The intestinal cæca in *P. micrococcus* syn. *P. sigmoides* Looss and *P. longipenis* Looss (1899) are shorter, ending quite in front of the ventral sucker. We accordingly create a new genus *Pleuropsolus* with *Pleuropsolus insolens* syn. *Phaneropsolus insolens* Bhalerao (1926) as the type species. *P. microon* should also be included in the new genus, which belongs to the subfamily Pleurogenetinæ, occupying an intermediate position between it and the Phaneropsolinæ, n. subf.

In the typical genera of the Pleurogenetinæ such as *Pleurogenes*, *Prosotocus*, *Mehraorchis*, and *Cryptotropa* the genital opening has moved from its preacetabular position far forwards but always towards the extreme left side, while in the genera *Parabascus*, *Limatulum*, *Mosesia*, *Postorchigenes* and *Brandesia* it has moved a little backwards and has come to occupy a position lateral to the acetabular zone. In the genus *Phaneropsolus* the genital pore has shifted much forwards straight

in the median line so as to lie immediately behind the pharynx. The subfamily *Phaneropsolinæ*, in which this genus is included, is also distinguished by the presence of a large cirrus sac, which does not extend behind the ventral sucker. In the small size of the cæca and the general topography, this subfamily stands near the *Lecithodendriinæ* and apparently connects it with the *Pleurogenetinæ*. In fact Looss (1899) and Lühe (1909) considered *Phaneropsolus* to be closely related to *Lecithodendrium* and *Pyconporus* when they first included these genera with *Brachycoelium* in the *Brachycoeliinæ*.

The genus *Anchitrema* Looss (1899) differs remarkably from all the *Lecithodendriidæ* in having a distinctly Y-shaped excretory bladder with the cornua about as long as the main stem. The intestinal cæca are long, reaching the hinder end and the testes lie symmetrically outside the cæca with the ovary behind them in the median line. These important differences justify the creation of a new subfamily *Anchitreminæ* for this genus, which appears to be closely related to the *Lecithodendriinæ* on account of the median preacetabular position of the genital opening, absence of the cirrus sac and habitat in bats. As is well known the Y-shaped excretory bladder in *Anchitrema* can be derived from the typical V-shaped condition met with in the family by the union of the cornua for a considerable part of their length from behind forwards.

Of all the *Lecithodendriidæ* *Exotidendrium* is the only genus which retains the two most important features supposed to have been present in the ancestor of the family, viz., median preacetabular position of the genital opening and presence of a well developed cirrus sac, the former characterising the *Lecithodendriinæ* and *Anchitreminæ*, the latter *Pleurogenetinæ*, *Phaneropsolinæ* and *Eumegacetinæ*. We believe that the *Pleurogenetinæ*, which occupy a central position arose as dominant members of the family primarily as parasites of Amphibia and Reptilia; later on other forms within this subfamily and constituting the subfamilies *Lecithodendriinæ*, *Anchitreminæ*, *Phaneropsolinæ* and *Eumegacetinæ* arose as parasites of mammals and birds possibly due to a similar diet of insects in which the larval stages of the distomes are found encysted.

Finally it may be remarked that the families *Lecithodendriidæ* and *Lepodermatidæ* are closely related, as the great range of variability in the topography of the genital organs and a tendency to a shifting of the genital opening from its primitive median preacetabular position towards anterior or antero-lateral direction shows. In our opinion the

*Lecithodendriidæ* represents the primitive forms, from which the *Lepodermatidæ* have been derived, as is evident from the predominantly V-shaped form of the excretory bladder met with in that family; besides there are *Lecithodendrine* forms such as *Eumegaceles*, *Anchitrema* and *Pleurogenes bicolor* with Y-shaped excretory bladder, which is typical of the *Lepodermatidæ*. From the meagre knowledge of the detailed excretory system available, we know that the position, number and arrangement of the common and accessory collecting tubes, capillaries and flame cells is also similar in the two families. The family *Dicrocoeliidæ* Odhner (1911) is evolved from the *Lepodermatidæ* which it closely resembles to a certain extent in the form of the excretory bladder, fundamental flame cell pattern of marita and the life cycle. Though the life history of the *Dicrocoeliidæ* and *Lecithodendriidæ* is practically unknown, it is expected that the miracidia of the families metamorphose into sporocysts and the xiphidiocercaræ with an unbranched tail represent the cercarial generation as in the *Lepodermatidæ*. Faust (1930) has on account of these probable resemblances included both the *Lepodermatidæ* and *Dicrocoeliidæ* in his superfamily *Dicrocoelioidea* in which we may provisionally include also the family *Lecithodendriidæ*. We, however, deem it necessary to point out that it is not proper in the present state of our meagre knowledge of the excretory system and life histories of these digenetic trematodes to break up the superfamily *Fascioloidea* Stiles and Goldberger, 1910, into the superfamilies *Echinostomoidea*, *Dicrocoelioidea*, *Heterophyoidea*, *Opisthorchoidea* and *Troglo-trematoidea* as Faust has done.

#### Family *Lecithodendriidae* Odhner, 1911

Family diagnosis:—Cuticle with or without spines. Excretory bladder V-shaped with or without short stem, rarely Y-shaped. Intestinal cæca of varying length. Genital opening median, submedian or sinistral, preacetabular or at the side of acetabulum. Testes symmetrically opposite or obliquely behind one another. Ovary dextral or median, pre- or post-testicular; receptaculum seminis and Laurer's canal present. Cirrus sac present, replaced by pseudocirrus sac, or absent; vesicula seminalis usually coiled: pars prostatica and prostate gland cells well developed. Uterus much coiled mostly post-testicular. Vitellaria of variable extent, pre- or post-equatorial. Eggs numerous, small, 0.015—0.06 long. Parasitic in the insecting eating vertebrates, from fishes to mammals.

Type genus: *Lecithodendrium* Looss, 1896.

**Key to the Subfamilies of Lecithodendriidae**

1. Cirrus sac absent; genital pore median or submedian ... ... ... ... 2  
Cirrus sac present, except in *Ganeo*; genital pore median or lateral ... ... 3
2. Excretory bladder Y-shaped; intestinal cæca long, reaching near hinder end ... ... *Anchitreminæ*  
Excretory bladder V-shaped, intestinal cæca short, not extending behind ventral sucker ... *Lecithodendriinae*
3. Genital pore lateral, usually to left side ... *Pleurogenetinæ*  
Genital pore median ... ... .. 4
4. Intestinal cæca long, extending behind ventral sucker, excretory bladder Y-shaped with short stem and long cornua provided with lateral branches ... *Eumegacetiinae*  
Intestinal cæca short, not extending behind ventral sucker; Excretory bladder V-shaped without lateral branches ... ... 5
5. Genital pore close behind pharynx; cirrus sac not extending behind ventral sucker; parasitic in birds and mammals ... *Phaneropsolinae*  
Genital pore preacetabular, behind intestinal bifurcation; cirrus sac extending much behind ventral sucker; parasitic in Crocodilia *Exotidendriinae*

**Anchitreminæ, n. subf.**

Subfamily diagnosis:—Lecithodendriidæ: Cæca long, reaching near hinder end. Excretory bladder Y-shaped with cornua about as long as stem. Genital pore median, preacetabular. Cirrus sac absent; vesicula seminalis long, coiled. Testes close behind ventral sucker, symmetrically opposite, outside cæca. Ovary somewhat median, just behind testes. Vitellaria extracæcal, post-testicular. Parasitic in intestine of bats and chameleon.

Type genus: *Anchitrema* Looss, 1899.

**Lecithodendriinae Looss, 1902.**

Subfamily diagnosis:—Lecithodendriidæ; Cæca short, never extending behind ventral sucker. Excretory bladder V-shaped. Genital pore

median or submedian, preacetabular. Cirrus sac absent, pseudocirrus sac present or absent; vesicula seminalis coiled. Parasitic in intestine of Chiroptera.

Type genus: *Lecithodendrium* Looss, 1896, sys. *Acanthatrium* Faust 1919, syn. *Prosthodendrium* Dollfus, 1931.

In this subfamily are included the genera *Lecithodendrium*, *Pycnoporus* Looss, 1899, *Mesodendrium* Faust, 1919, *Castroia* Travassos, 1928, and *Lecithoporus* n.g., with the type species *Lecithoporus (Pycnoporus) inversus* Looss, 1907. To this new genus are also assigned *P. microlaimus* Linstow, 1894, and *P. indicus* Pande, 1935. The genus *Lecithoporus* is distinguished from *Pycnoporus* by the cylindrical or nearly cylindrical shape of the body, absence of spines on the body wall, small size of the ventral sucker, large size of the oral sucker and the uterus passing in the testicular zone partly or completely overlapping the testes. The new genus obviously stands between *Lecithodendrium* and *Pycnoporus*.

#### Key to the genera of the subfamily Lecithodendriinae.

1. Body reniform almost twice as broad as long... *Castroia*
- Body not twice as broad as long ... ... 2
2. Body wall covered with spines; acetabulum very large and powerful ... ... ... *Pycnoporus*
- Body wall without spines; acetabulum small... 3
3. Body nearly cylindrical; uterus passing in testicular zone ... ... ... ... *Lecithoporus*
- Body pear-shaped or rounded, exceptionally sub-cylindrical; uterine convolutions post-testicular ... ... ... ... 4
4. Vitellaria pre-testicular ... ... ... ... *Lecithodendrium*
- Vitellaria post-testicular ... ... ... ... *Mesodendrium*

#### *Pleurogenetinae* Looss, 1899

Subfamily diagnosis:—Lecithodendriidæ: Cæca of varying length. Excretory bladder V-shaped, with or without short stem, rarely Y-shaped. Genital pore lateral, preacetabular to left side near body margin, or at the side of acetabulum. Cirrus sac present except in *Ganeo*; vesicula seminalis usually coiled. Parasitic in Amphibia, Reptilia, birds and bats, rarely fishes.

Type genus: *Pleurogenes* Looss, 1896.

In this subfamily are included the genera *Pleurogenes*, *Prosotocus* Looss, 1899, *Brandesia* Stoss, 1899, *Ganeo* Klein, 1905, *Parabascus* Looss, 1907, *Limatulum* Trav., 1921, *Mosesia* Trav., 1928, *Cryptotropa* Strand, 1928, (Syn. *Cryptotrema* Ozaki, 1926) *Postorchigenes* Tubangui, 1928, *Mehraorchis* Srivastava, 1934, and *Pleuropsolus* n.g.

*Distomum limatum* Braun, 1900, belongs to the genus *Parabascus* Looss. The recent account of this species given by Modlinger (1930) leaves no doubt whatever about the inclusion of this species in the genus *Parabascus*. Looss (1907) himself had pointed out the close resemblance of this species with *Parabascus lepidotus*, even though he considered Braun's description to be incomplete. The skin is spinose and the ventral sucker is twice the size of the oral sucker as in the latter species. The intestinal cæca also have exactly the same course, ending a little in front of the hinder end. The testes, cirrus sac, ovary and vitellaria also occupy exactly the same position in both. As *Distomum limatum* is assigned to *Parabascus* under the name of *P. limatum* Braun, 1900, the genus *Limatulum* then contains only one species *L. oklamomensis* Macy, 1932, which thus becomes the type species. The account of this species tallies closely with the diagnosis of the genus given by Stiles and Nolan in their Key Catalogue, 1931.

#### Key to the genera of the subfamily Pleurogenetinae

1. Genital pore much preacetabular, sinistral ... A  
Genital pore lateral to acetabular zone ... B
- A. Cirrus sac absent; pseudocirrus sac present or  
absent ... ... ... ... *Ganeo.*  
Cirrus sac present ... ... ... ... 2
2. Ovary partly or completely behind testes ... 3  
Ovary partly or completely in front of testes ... 4
3. Testes partly or completely in front of cirrus  
sac; never occur in cysts ... ... ... *Prosotocus*  
Testes partly or completely behind cirrus sac;  
occur in cysts ... ... ... ... *Mehraorchis*
4. Genital pore close in front of acetabulum  
slightly to left ... ... ... ... *Pleuropsolus*  
Genital pore much in front of acetabulum, near  
left body margin ... ... ... ... 5
5. Vitellaria limited to anterior half; ova without  
projection ... ... ... ... *Pleurogenes*

Vitellaria profusely developed from pharangeal level to posterior end of body; ova with small stump-like projection	...	...	<i>Cryptotropa</i>
B. Testes preacetabular, pre-equatorial; ovary post-testicular; parasitic in frogs	...	...	<i>Brandesia</i>
Testes post-acetabular, equatorial or post-equatorial; ovary pretesticular or partly in testicular zone; parasitic in lizards, birds and mammals	...	...	1
1. Cæca long, extending behind centre of body; suckers very unequal	...	...	2
Cæca short; suckers subequal	...	...	3
2. Acetabulum smaller than oral sucker; parasitic in lizards ( <i>Hemidactylus</i> )	...	...	<i>Postorechigenes</i>
Acetabulum about twice as large as oral sucker; parasitic in Chiroptera	...	...	<i>Purabascus</i>
3. Testes and ovary lobed; acetabulum pre-equatorial; parasitic in birds	...	...	<i>Mosesia</i>
Testes and ovary entire; acetabulum nearly equatorial; parasitic in Chiroptera	...	...	<i>Limatulum</i>

### Phaneropsolinae, n. subf.

Subfamily diagnosis.—*Lecithodendriidae*: Cuticle covered with spines. Oesophagus small; intestinal cæca small, sac-shaped, ending in front of ventral sucker. Excretory bladder large, V-shaped. Genital opening median far forward, close behind pharynx. Testes symmetricaly opposite, in front of or in level with ventral sucker. Cirrus sac strikingly long, not extending behind ventral sucker; vesicula seminalis bipartite or coiled; pars prostatica long. Ovary to left side in level with or close behind testes; receptaculum seminis large, behind ovary. Vitellaria in anterior body, in front of testes and acetabulum. Parasitic in birds and mammals.

Type genus: *Phaneropsolus* Looss, 1899.

### Exotidendiinae, n. subf.

Subfamily diagnosis.—*Lecithodendriidae*: Cuticle covered with spines. Prepharynx well developed; oesophagus long; intestinal cæca small, not extending behind ventral sucker. Excretory bladder V-shaped. Genital pore median, a little in front of ventral sucker, close

behind intestinal bifurcation. Testes lateral, nearly opposite, at about middle of body, post-caecal, preovarian. Cirrus sac very long extending much behind ventral sucker; vesicula seminalis straight; pars prostatica large, bifid; cirrus long, cylindrical, armed with large rose thorn-shaped spines. Ovary median or a little lateral, near basal end of cirrus sac, a little in front of hinder end; receptaculum seminis large, behind ovary; metraterm large, saccular, armed with spines. Ova with polar filament. Vitellaria post-caecal, consisting of follicles scattered across entire body from acetabulum to hinder end. Parasitic in Crocodilia.

Type genus: *Exotidendrium*, n. g.

#### **Eumegacetinae, n. subf.**

Subfamily diagnosis.—*Lecithodendriidae*: Body very muscular; body wall without spines. Suckers very large and muscular. Oesophagus nearly absent; cæca long, extending behind ventral sucker. Excretory bladder Y-shaped with small stem and long cornua with lateral branches. Ovary post-testicular. Testes lateral, opposite, near body wall. Cirrus sac in level with or just in front of testes; vesicula seminalis coiled. Genital pore median, at hinder end of pharynx. Parasitic in cloaca and rectum of birds.

Type genus: *Eumegacetus* Looss, 1900, Syn. *Megacetus* Looss, 1899.

#### **Eumegacetus artamii, n. sp.**

Only one specimen of this distome was obtained from the rectum of one of the four Ashy Swallow-Shrike *Artamus fuscus* examined at Allahabad.

Body elongated, somewhat elliptical, rounded at anterior end, bluntly pointed at posterior end, 5 in length and 2·1 in maximum breadth in region of testes; breadth at centre of oral sucker 1·3, behind ventral sucker in region of ovary 1·8. Suckers large, equal, with rounded openings; oral sucker much stronger than ventral sucker, subterminal, entirely ventral, 0·8 in length and 0·9 in breadth; ventral sucker slightly post-equatorial with large opening, 0·9 in diameter. Prepharynx absent; pharynx stout, 0·3 in length, 0·5 in breadth; oesophagus absent; cæca first pass outwards transversely and then bend near body wall to continue their downward course, much overlapped by uterine coils and vitellaria, terminating a little in front of hinder end.

Genital opening median, immediately behind pharynx, a little in front of testicular zone. Testes lateral, inside cæca, symmetrically opposite, pre-equatorial about half way between pharynx and ventral sucker, of varying shapes due to pressure of uterine mass; right testis 0·7 long and 0·36

broad, left 0·6 long and 0·56 broad. Cirrus sac to right of median line, close in front of and inside right testis partly coinciding with its zone, saccular behind and slightly crescent-shaped in anterior one-third part on

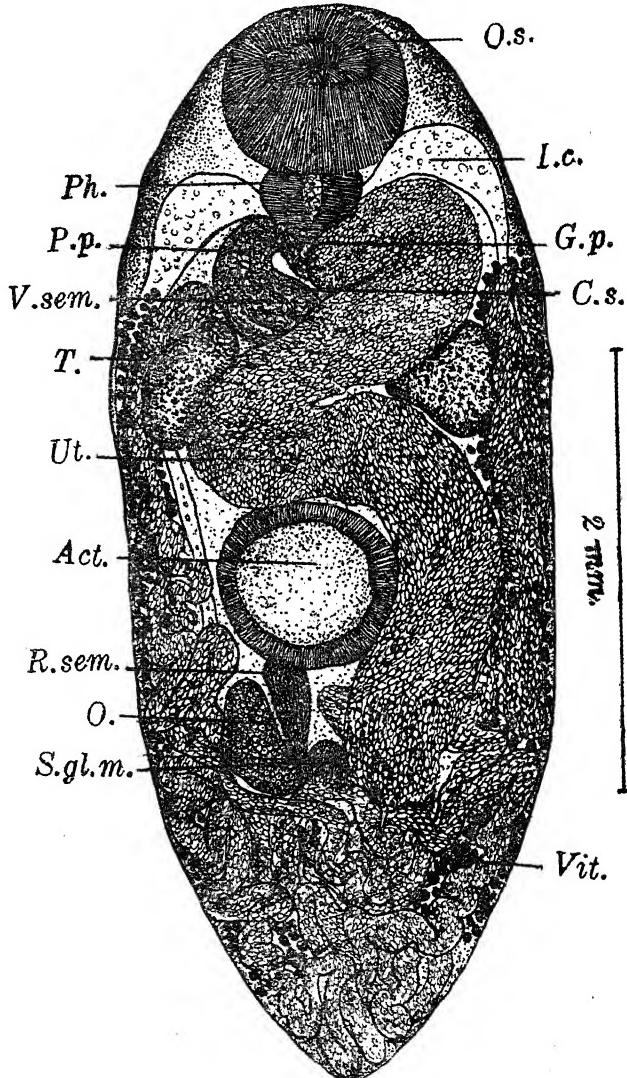


Fig. 2.—Ventral View of *Eumegacetes artamii*, n. sp.

account of concavity on its inner side, 0·63 in length and 0·59 in maximum breadth near basal end; vesicula seminalis coiled, 0·11 in maximum breadth; pars prostatica 0·3 in length and 0·068 in maximum breadth; cirrus short. Ovary immediately behind ventral sucker to right side, 1·5 in

front of hinder end, longer than broad, 0'66 in length and 0'3 in maximum breadth; shell gland mass median inside posterior part of ovary; receptaculum seminis pear-shaped, between ventral sucker and shell gland mass inside ovary, 0'5 in length and 0'21 in greatest breadth. Uterus passes behind ovary to hinder end, filling post-ovarian part with convolutions mostly transversely arranged; anteriorly it passes a little in front of testes and consists of three parts, a large, massive, saccular, S-shaped intracæcal part, which opens at genital pore and two narrow, longitudinal parts composed of short windings, restricted to lateral regions on and outside cæca and extending a little in front of testes; metraterm absent. Vitellaria lateral, composed of small follicles not arranged in groups, overlapping cæca, intra and extracæcal, from level of genital opening or a little in front of testes to a little in front of hinder end; transverse vitelline ducts run obliquely backwards, right on ventral surface of ovary and left covered by large intracæcal uterine mass; vitelline reservoir near hinder margin of shell gland mass. Ova numerous, yellow brown, oval and narrow pointed at one end, 0'0238—0'0272 in length and 0'0136 in maximum breadth. Excretory bladder Y-shaped with small stem and long cornua, ending anteriorly a little beyond anterior limit of vitellaria, just behind level of genital opening; lateral branches not observed.

*Remarks* :—*Eumegacetus artamii*, n. sp. resembles, *E. emendatus* Braun, 1901, syn. *Megacetus triangularis* Looss, 1899, in the elongated elliptical shape of the body, position of the testes and ovary, slightly semilunar shape of the cirrus sac and to a great extent in the length of the vitellaria. It, however, differs in the size of the body and suckers, presence of a large massive S-shaped intracæcal part of uterus and the vitellaria extending more forwards, i.e., a little in front of the testes (in *E. emendatus* vitellaria do not extend in front of middle of testes). The cirrus sac in the new species is larger, somewhat ovoid, slightly semilunar near distal end, whereas in *E. emendatus* it is a little swollen near basal end and distinctly U-shaped. Besides, the cirrus sac in the former lies in front of the testes and not between them as in *E. emendatus*.

Host—*Artamus fuscus*.

Habitat—Rectum.

Locality—Allahabad.

#### ***Eumegacetus braunii*, n. sp.**

Only one specimen was obtained from the cloaca of an Ashy Swallow-Shrike *Artamus fuscus* at Allahabad. Body egg-shaped with broad

anterior and narrow posterior ends. Length 2·2, greatest breadth 1·4 at about middle of body length, i.e., a little in front of acetabulum. Suckers large and very muscular, nearly equal with circular openings; oral sucker subterminal, entirely ventral with small opening directed forwards, broader than long, 0·63 in length and 0·72 in maximum breadth; ventral sucker rounded, post-equatorial at about two-third body length from anterior end, 0·666 in diameter with large opening. Pharynx stout, 0·18 in length and 0·28 in maximum breadth; oesophagus absent; intestinal cæca as usual in the genus, ending a little in front of hinder end.

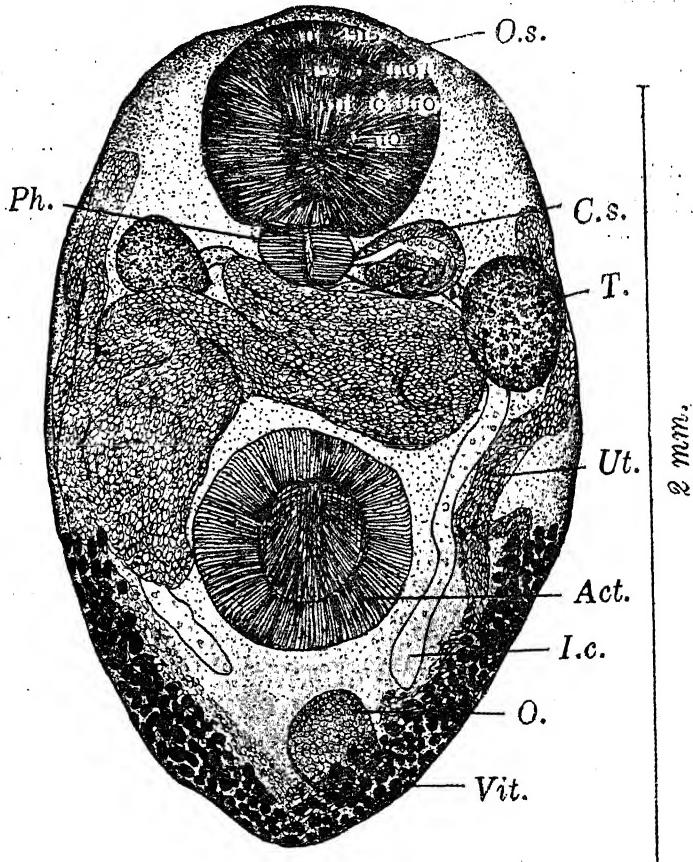


Fig. 3.—Dorsal View of *Eumegacetes braunii*, n.sp.

Genital opening median just in front of hinder end of pharynx in testicular zone. Testes ovoid, lateral near body wall, opposite each other, preacetabular, pre-equatorial, partly or almost completely in level with pharynx; right testis 0·37 in length and 0·27 in breadth, left testis

0·23 in length and 0·27 in breadth. Cirrus sac to right side in pharyngeal zone, in front of and partly in zone of right testis, nearly ovoid, broader than long, 0·23 in length and 0·3 in breadth; vesicula seminalis coiled; pars prostatica oval; cirrus small. Ovary somewhat rounded, post-acetabular a little in front of hinder end, 0·3 in length 0·27 in breadth; receptaculum seminis and Laurer's canal not seen; shell gland mass median, inside anterior half of ovary, a little behind ventral sucker. Uterus mainly confined to lateral regions near body wall from hinder end to a little in front of pharynx with a huge intracæcal saccular mass more or less of the shape of an Oligochaete nephridium, situated to left side and in front of acetabulum, filling almost entire preacetabular region up to pharynx between testes; metraterm absent. Vitellaria lateral, from a little behind anterior margin or middle of acetabulum to hinder end of body, overlapping lateral uterine coils and partly ovary and uniting behind the latter at hinder end. Ova numerous, yellow brown, oval and narrow pointed at opercular end, 0·0255—0·0272 in length and 0·0102—0·0136 in maximum breadth.

*Remarks* :—*Eumegacetus braunii*, n. sp. resembles *E. contribulans* Braun, 1901, and *E. medioximus* Braun, 1901, in size and shape of body, size of the suckers and pharynx, and in the vitellaria being confined to the posterior half, i.e., behind the testes. Besides, it resembles *E. medioximus* in the forward limit of the vitellaria and to *E. contribulans* to a certain extent in the configuration of the uterus. But it differs from both in the position of the ovary near the hinder end and absence of the metraterm. It differs further from *E. contribulans* in the post-equatorial position of the ventral sucker, and from *E. medioximus* in the configuration of the uterus. In the size of its body, post-equatorial position of the ventral sucker and position of the ovary near hinder end *E. braunii* resembles *E. perodiosus* Travassos, 1922, but it is sharply separated from the latter on account of the pre-equatorial position of the testes, restricted length of the vitellaria (in *E. perodiosus* vitellaria extend from testicular zone to ovarian zone) and configuration of the uterus.

Host—*Artamus fuscus*.

Habitat—Cloaca.

Locality—Allahabad.

#### Key to the Species of the Genus *Eumegacetus* Looss, 1900.

Vitellaria extending anteriorly to testes or a little  
in front ... ... ... A.

- Vitellaria not reaching testes ... ... B.
- A. Oral sucker larger than ventral sucker; testes equatorial, testicular zone partly coinciding with acetabular zone ... ... *E. perodiosus*  
Trav. 1922.
- Suckers of nearly equal size; testes pre-equatorial, preacetabular ... ... 1.
1. Acetabulum equatorial, cirrus sac slightly swollen at base, more or less U-shaped, mostly in testicular zone ... ... *E. emendatus*  
Braun, 1900.
- Acetabulum post-equatorial; cirrus sac much swollen at base, slightly crescent-shaped anteriorly, mostly in front of testicular zone ... ... *E. artamii*, n. sp.
- B. Acetabulum equatorial; vitellaria hardly extend in front of hinder margin of acetabulum ... ... *E. contribulans*  
Braun, 1901.
- Acetabulum post-equatorial; vitellaria extend up to or in front of anterior margin of acetabulum ... ... 1.
1. Testes behind pharangeal zone; ovary immediately behind acetabulum ... ... *E. medioximus*  
Braun, 1901.
- Testes partly or entirely in pharangeal zone, ovary near hinder end ... ... *E. brununii*, n. sp.

#### SUMMARY

The account of a new genus *Exotidendrium* from the Indian gharial *Gavialis gangeticus* and two new species of the genus *Eumegacetes* Looss from an Ashy Swallow-Shrike is given.

The genus *Exotidendrium* belongs to the family Lecithodendriidae, but it is distinguished from all the genera in the great size of the cirrus sac and its position with regard to the testes and ovary, straight vesicula seminalis, long pars prostatica, strongly developed cirrus armed with large rose thorn-shaped spines, position of the ovary and receptaculum seminis near the hinder end, a large saccular metraterm armed with scattered spines and ova provided with a polar filament. It stands closer to the subfamily Lecithodendriinae on account of the median preacetabular position of the genital opening, while in the possession of a large

cirrus sac it resembles the subfamily Pleurogenetinæ, but as it differs in certain important features from both these subfamilies, a new subfamily Exotidendriinæ is created for it.

In the discussion on the classification of the family Lecithoden-driidæ the family Eumegacetidæ Travassoss is reduced to the rank of a subfamily; new subfamilies Anchitreminæ for the genus *Anchitrema* and Phaneropsolinæ for the genus *Phaneropsolus* are created. Two new genera *Pleuropsolus* with the type species *P. insolens* syn. *Phaneropsolus insolens* Bhalerao and *Lecithoporus* with the type species *Lecithoporus (Pycnoporus) inversus* Looss are created. The relationships of the various subfamilies are discussed and finally it is shown that the families Lecithodendriidæ, Lepodermatidæ and Dicrocoelidæ are closely related. A classification of the family with diagnosis and keys to the subfamilies and genera is given. Key to the species of the genus *Eumegacetes* is given.

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